HEAT TREATMENT OF S.G CAST IRON AND ITS EFFECTS

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

Bachelor of Technology
In
Metallurgical and Materials Engineering

By

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Department of Metallurgy and Materials Engineering
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UNDER THE GUIDANCE OF
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Certificate

This is to certify that the thesis entitled, "**Heat Treatment of S.G Cast Iron**" submitted by **Sudhanshu Shekhar** & **Amit Jaiswal** 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 them, 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.

Prof. Dr. S.Sen.

Date:
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CONTENT

ABSTRACT

S.G Cast iron is defined as a high carbon containing, iron based alloy in which the graphite is present in compact, spherical shapes rather than in the shape of flakes, the latter being typical of gray cast iron . As nodular or spheroidal graphite cast iron, sometimes referred to as ductile iron, constitutes a family of cast irons in which the graphite is present in a nodular or spheroidal form. The graphite nodules are small and constitute only small areas of weakness in a steel-like matrix. Because of this the mechanical properties of ductile irons related directly to the strength and ductility of the matrix present—as is the case of steels.

One reason for the phenomenal growth in the use of Ductile Iron castings is the high ratio of performance to cost that they offer the designer and end user. This high value results from many factors, one of which is the control of microstructure and properties that can be achieved in the as-cast condition, enabling a high percentage of ferritic and pearlitic structure.

Heat treatment is a valuable and versatile tool for extending both the consistency and range of properties of Ductile Iron castings beyond the limits of those produced in the as-cast condition. Thus, to fully utilize the potential of Ductile Iron castings, the designer should be aware of the wide range of heat treatments available for Ductile Iron, and its response to these heat treatments.

The most important heat treatments and their purposes are:

Stress relieving - a low-temperature treatment, to reduce or relieve internal stresses remaining after casting
Annealing - to improve ductility and toughness, to reduce hardness and to remove carbides
Normalizing - to improve strength with some ductility
Hardening and tempering - to increase hardness or to give improved strength and higher proof stress ratio
Austempering - to yield bainitic structures of high strength, with significant ductility and good wear resistance
Surface hardening - by induction, flame, or laser to produce a local wear-resistant hard surface

Although Ductile Iron and steel are superficially similar metallurgically, the high carbon and silicon levels in Ductile Iron result in important differences in their response to heat treatment. The higher carbon levels in Ductile Iron increase hardenability, permitting heavier sections to be heat treated with lower requirements for expensive alloying or severe quenching media. These higher carbon levels can also cause quench cracking due to the formation of higher carbon martensite, and/or the retention of metastable austenite. These undesirable phenomena make the control of composition, austenitizing temperature and quenching conditions more critical in Ductile Iron. Silicon also exerts a strong influence on the response of Ductile Iron to heat treatment. The higher the silicon content, the lower the solubility of carbon in austenite and the more readily carbon is precipitated as graphite during slow cooling to produce a ferritic matrix.

Although remaining unchanged in shape, the graphite spheroids in Ductile Iron play a critical role in heat treatment, acting as both a source and sink for carbon. When heated into the austenite temperature range, carbon readily diffuses from the spheroids to saturate the austenite matrix. On slow cooling the carbon returns to the graphite "sinks", reducing the carbon content of the austenite. This availability of excess carbon and the ability to transfer it between the matrix and the nodules makes Ductile Iron easier to heat treat and increases the range of properties that can be obtained by heat treatment.

Austempered Ductile Irons (ADI) are the most recently developed materials of the DI family. By adapting the austempering treatment initially introduced for steels to DI, it has been shown that the resulting metallurgical structures provide properties that favorably compare to those of steel while taking advantage of a near-net-shape manufacturing process.

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INTRODUCTION

"Iron seemeth a simple metal but in its nature are many mysteries"

After three hundred years of progress, the above words of Joseph Glanville are still true. Knowledge is certainly preferable to speculation. And yet, the approach towards solving a given practical problem will be confusing and haphazard without the guidance of ideas on at least what may take place during solidification. Willing or not, one must depend, in part, on hypotheses.

Developed in 1943, it was found that by adding magnesium before pouring caused the graphite to form nodules rather than flakes. This resulted in a new material, with excellent tensile strength and ductility. Adding these mechanical properties of this material to the advantages already offered by cast iron soon led to it finding its way into virtually every mainstream area of engineering, in many cases replacing existing steel castings or forgings due to achievable cost savings.

S.G Cast iron or Ductile Iron (DI) is an iron-carbon alloy having structure of nodules of graphite embedded in steel matrix. It derives its name as it has graphite in the form of spheroids embedded in the steel matrix, normally of ferritic, or pearlitic. These nodules of graphite are formed directly from the liquid during the process of solidification. The nodules are more regular, sharp and compact sphere.

The matrix of ductile irons can be varied from a soft and ductile ferritic structure, through harder and higher strength pearlitic structures to a hard, higher and comparatively tough tempered martensitic or bainitic structure. Thus, a wide range of combinations of strength and ductility can be achieved. General engineering grades of ductile iron commonly have the structures which are ferritic, ferritic/pearlitic or pearlitic.

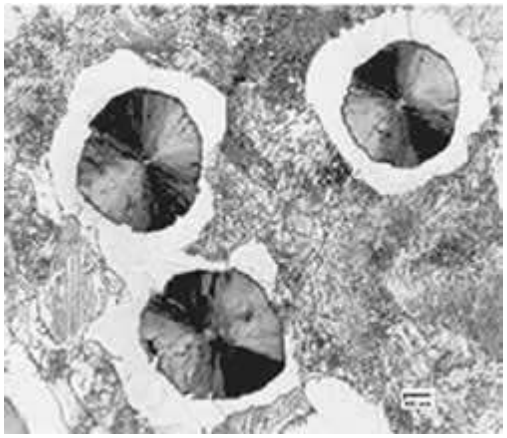
Controlled processing of the molten iron precipitates graphite as spheroids rather than flakes. The round shape of the graphite eliminates the material's tendency to crack and helps prevent cracks from spreading.

Control of matrix structure:→ The main trace elements present in ductile iron can have a marked influence on the structure and hence the properties of the iron
With the exception of silicon, all elements promote pearlite and all elements with the exception of silicon, nickel and copper also promotes carbides.

The strength properties of ferritic ductile iron are generally increased by the elements, which go in to the solution. With the exception of carbon, all the elements increase tensile strength and hardness. An example of the extent to which ferrite is affected by solid solution strengthening is illustrated for the elements silicon and nickel.
A 1% addition of silicon raises the proof and tensile strength of a ferritic iron by approximately 82 N/mm2 whereas 1% of nickel increases these properties by 46 N/mm2. In the ferritic irons increase in tensile strength and proof strength are obtained at the expense of ductility and in such case the iron can become embrittled.

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.

S.G Iron (Ductile Iron)



SG Iron Microstructure

FIG. 1.1 The graphite in spheroidal form in the microstructure Of s.g cast iron

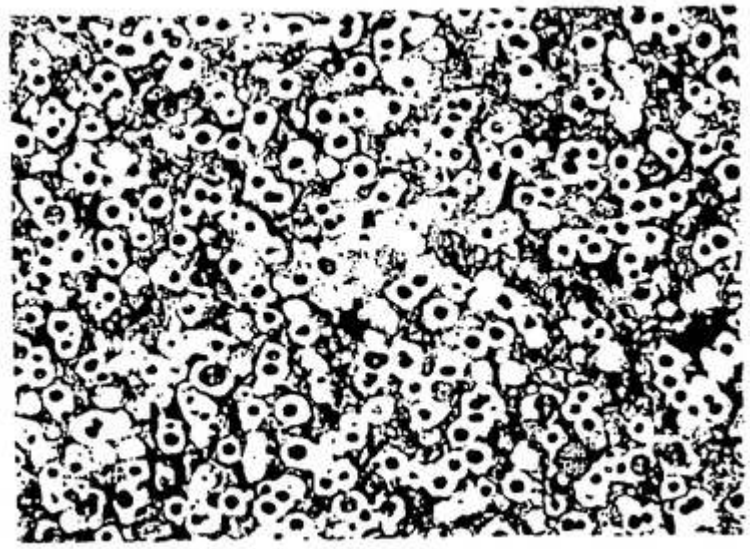


Fig.:1.2 The microstructure of S.G cast iron

HOW IS S.G CAST IRON PRODUCED??

It is produced by treating the molten alloy with magnesium, or cerium , or a combination of two elements, or such elements like Ca, Ba, Li, Zr causing spheroidal graphite to grow during solidification. Use of magnesium to have 0.04-0.06% residual content is more easy to adopt and economical, which is followed by addition of ferro-silicon. Certain elements , if present, like 0.1% Ti, 0.009% Pb, 0.003% Bi, 0.004% Sb prevent the production of S.G iron , but their effect can be removed by adding 0.005-0.01% Ce. For most raw materials, combined use of Mg and Ce (it improves magnesium recovery) followed by ferro silicon as inoculant is made to produce S.G Iron.

STEPS IN PRODUCTION OF S.G IRON

1. **Desulphurisation :** Sulphur helps to form graphite as flakes . Thus, the raw material for producing S.G Iron should have low sulphur (less than 0.1%), or remove sulphur from iron during melting, or by mixing iron with a desulphurising agent such as calcium carbide, or soda ash (sodium carbonate).

2. **Nodulising :** Magnesium is added to remove sulphur and oxygen still present in the liquid alloy and provides a residual 0.04% magnesium, which causes growth of graphite to be spheroidal, probably the interface energy becomes high to have a dihedral angle of 180 degree,(in simple term the graphite does not wet the liquid alloy.). Magnesium treatment desulphurises the iron to below 0.02% S, Before alloying it. Magnesium and such elements have strong affinity for sulphur , and thus scavenge sulphur from the molten alloy as an initial stage for producing S.G Iron. These additions are expensive to increase the cost of S.G Iron produced. Thus sulphur of molten alloy(or the raw material used), before nodulising, should be kept low.

   Magnesium is added when melt is near 1500 degree centigrade, but magnesium vaporizes at 1150 degree centigrade. Magnesium being lighter floats on the top of the bath, and being reactive burn off at the surface. In such cases magnesium is added as Ni-Mg, Ni-Si-Mg alloy or magnesium coke to reduce the violence of the reaction and to have saving in Mg.

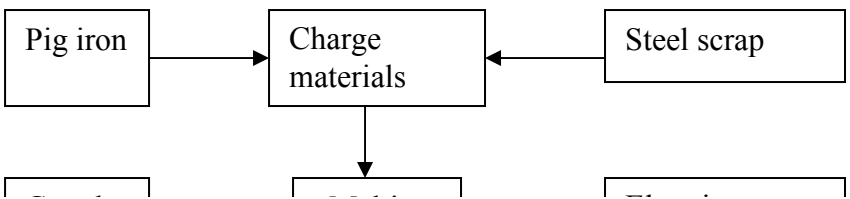
3. **Inoculation :** As magnesium is carbide former, ferrosilicon is added immediately as innoculant. Remelting causes reversion to flake graphite due to loss of magnesium.

Stirring of molten alloy after addition of nodulising element evolves a lot of gas, which gets dissolved in liquid alloy, and forms blow-holes in solid casting. The contraction during solidification of nodular cast iron castings is much greater than that of gray iron castings, which needs careful design of moulds to avoid shrinkage cavities in solidified castings.

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 %

Process routes used in the production of ductile iron:→



PROPERTIES OF S.G CAST IRON

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.

Properties

Easy to cast
The high fluidity of the metal in its molten state makes it ideal for the casting process

Strength
Tensile strengths of up to 900N/mm2 (ADI gives the option of higher strengths).

Ductility
Elongations of in excess of 20% (*Lower grades only*)

Excellent Corrosion Resistance
when compared to other ferrous metals.

Ease of Machining
Free graphite in the structure also lends itself to machining (chip formation).

Cost per Unit Strength
Significantly cheaper than most materials

Effect of alloying elements on the properties of ductile iron:→

2). **Manganese:→** As it is a mild pearlite promoter, with some required properties like proof stress and hardness to a small extent. As Mn retards the onset of the eutectoid transformation, decreases the rate of diffusion of C in ferrite and stabilize cementite (Fe3C).But the problem here is the embrittlement caused by it, so the limiting range would be 0.3-1.0

1**). Silicon**:→ As the Si in the ductile iron matrix provides the ferritic matrix with the pearlitic one.

Silicon enhances the performance of ductile iron at elevated temperature by stabilizing the ferritic matrix and forming the silicon reach surface layer, which inhibits the oxidation

The potentially objectionable influences of increasing silicon content are:→ 1). Reduced impact test energy. 2). Increased impact transition temperature. 3). Decreased thermal conductivity.

Si is used to promote ferrite and to strengthen ferrite. So Si is generally held below 2.2% when producing the ferritic grades and between 2.5% and 2.8% when producing pearlitic grades

3). **Copper**: → It is a strong pearlite promoter. It increases the proof stress with also the tensile strength and hardness with no embrittlement in matrix. So in the pearlitic grade of the ductile iron the copper is kept between 0.4-0.8% and is a contaminant in the ferritic grade.

4**). Nickel**:→ As it helps in increasing the U.T.S without affecting the impact values .So it can be in the range of 0.5-2.0. It strengthens ferrite, but has much less effect than Silicon in reducing ductility. But there is the danger of embrittlement with the large additions; in excess of 2%.Due to the high cost it is generally present as traces in the matrix.

5). **Molybdenum:→**It is a mild pearlite promoter. Forms intercellular carbides especially in heavy sections. Increases proof stress and hardness. Danger of embrittlement, giving low tensile strength and elongation value. And it also improves elevated temperature properties.

6**). Chromium**:→ As it prevents the corrosion by forming the layer of chromium oxide on the surface and stops the further exposition of the surface to the atmosphere. But as it is a strong carbide former so not required in carbide free structure and <1% required in the grade of GGG-50 .it is kept around 0.05% Maximum.

8).**Sulphur and Phosphorus**:→As 'P' is kept intentionally very low, as it is not required because it causes cold shortness and so the property of ductile iron will be ruined. But the addition of S is done for better machinability, but it is kept around 0.009 and maximum 0.015%.As the larger additions of Sulphur may cause the hot (red) shortness.

Magnesium treatment

Why magnesium:→ Research work has shown that on a laboratory scale additions of a number of elements are capable of producing spheroidal graphite structures in the cast irons. These elements include magnesium, cerium, calcium and yttrium. However, owing to a number of factors the application of these elements on a production scale has been restricted to the element magnesium, although it is claimed that in Japan calcium based alloys are used for producing ductile iron castings. 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.

The use of cerium results in nodular graphite structures, with certain type of metal compositions, but these restrictions and the general inconsistency of the process again makes it unsuitable for large-scale application. However, the benefits of including a small amount of cerium in the nodularising process in order to offset the subversive nature of contaminating elements such as lead, antimony and titanium are well known, and the majority of ductile iron is produced using the cerium-bearing magnesium alloys.

Carbide in the structure: → S.G iron castings are more prone to contain carbides than flake-graphite castings of similar section and size and carbon and silicon contents. This occurs partly because the spherodizing process generally involves the addition of magnesium and/or cerium, which are both elements that to promote the formation of eutectic carbide; and partly because the sequence of solidification produced by the growth of nodular graphite tend to promote undercooling during solidification to temperatures at which white iron structure as likely to form by heat treatment.

The presence of carbide in ductile iron is undesirable for a number of reasons:

- It increases the tendency to form shrinkage porosity and thus increases the feeding requirements during casting.
- It increases the risk of cracking during knockout and fettling.
- It decreases the ductility of the iron.
- It drastically reduces the impact resistance.
- It increases hardness and reduces machinability.

It requires heat treatment to 900-920oC to remove the carbide.
High silicon levels are also beneficial but the potential embrittling action of silicon contents much above about 2.6% should not be overlooked.

Factors that affect the properties of the S.G Cast iron: →

1). **Graphite structure:**→ Graphite occupies about 10-15% of the total material volume. And it's presence is to reduce the effective cross sectional area .The amount and form of the graphite in the ductile iron are determined during solidification and cannot be altered by subsequent heat treatment. All of the mechanical and physical properties of this class of materials are a result of the graphite being substantially or wholly in the in the spheroidal nodular shape, and any departure from this shape in a proportion of the graphite will cause some deviation from these properties.

All properties relating to the strength and ductility decreases as the proportion of non nodular graphite increases, and those relating to the failure, such as proof strength. The form of non-nodular graphite is important because thin flakes with sharp edges have a more adverse effect on the strength properties than compacted forms of graphite with round ends. For this reason, visual estimates of percentage of nodularity are rough guide to properties.

2). **Graphite amount**: → As the amount of graphite increases, there is relatively small decrease in strength and elongation, in modulus of elasticity, and in density. In general these effects are small compared with the effects of other variables because the carbon equivalent content of spheroidal graphite iron is not a major variable and is generally maintained close to the eutectic value.

3). **Matrix structure**:→ The principal factor in determining the different grades of ductile iron in the specifications is the matrix structure. In the as cast condition, the matrix will consist of varying proportions of pearlite and ferrite, and as the amount of pearlite increases, the strength and hardness of the iron also increases. The proportions of ferrite and pearlite in the matrix principally determine ductility and impact properties.

The matrix structure can be change by heat treatments, and those most often carried out are annealing to produce a fully ferritic matrix, and normalizing to produce a substantially pearlitic matrix.

In general annealing produces a more Ductile matrix with a lower impact transition temperature than is obtained in as-cast ferritic irons.

4). **Section size**:→ As the section size decreases, the solidification and cooling rates in the mould increases. This results in a fine grain structure that can be annealed more rapidly. In thinner sections, however, carbides may be present, which will increase hardness, decrease machinability, and lead to brittleness. To achieve soft ductile structures in thin sections, heavy inoculation, probably at a last stage, is desirable to promote graphite formation through a high nodule number.
As the section size increases, the nodule number decreases, and micro segregation becomes more pronounced. This results in a large size of nodule size, a reduction in the proportion of as cast ferrite, and increasing resistance to the formation of a fully ferritic structure upon annealing.

5). **Composition:**→ In addition to the effects of elements in stabilizing pearlite or retarding transformation (which facilitates heat treatment to change matrix structure and properties), certain aspects of composition have an important influence on some properties. Silicon hardens and strengthens ferrite and raises its impact transition temperature; therefore, silicon content should be kept low as practical, even below 2%, to achieve maximum ductility and toughness.
Nickel also strengthens ferrite, but has much less effect than silicon in reducing ductility. When producing as-cast grades of iron requiring fairly ductility and strength such as ISO GRADE 5007, it is necessary to keep silicon low to obtain high ductility, but it may also be necessary to add some nickel to strengthen the iron sufficiently to obtain the required tensile strength. Almost all elements present in trace amounts combine to reduce ferrite formation, and high-purity charges must be used for irons to be produced in the ferritic as cast-condition.

Similarly, all carbide forming elements and manganese must be kept low to achieve maximum ductility and low hardness. Silicon is added to avoid carbides and to promote ferrite as-cast in thin sections.
The electrical, magnetic, and thermal properties of Ductile irons are influenced by the by the composition of the matrix. In general, as the amount of alloying elements increases and thermal conductivity deceases.

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 OF S.G CAST IRON

Nodular cast irons (or ductile, or spheroidal graphite iron) are primarily heat treated to create matrix microstructures and associated mechanical properties not readily obtained in the as-cast condition. As-cast matrix microstructures usually consist of ferrite or pearlite or combinations of both, depending on cast section size and/or alloy composition.

The normalizing, hardening, and austempering heat treatment, which involve austenitization, followed by controlled cooling or isothermal reaction, or a combination of the two, can produce a variety of microstructures and greatly extend the limits on the mechanical properties of ductile cast iron.

These microstructures can be separated into two broad classes:

- Those in which the major iron-bearing matrix phase is the thermodynamically stable body-centered cubic (ferrite) structure

- Those with a matrix phase that is a meta-stable face-centered cubic (austenite) structure. The former are usually generated by the annealing, normalizing, normalizing and tempering, or quenching and tempering processes. The latter are generated by austempering, an isothermal reaction process resulting in a product called austempered ductile iron (ADI).

Other heat treatments in common industrial use include stress-relief annealing and selective surface heat treatment. Stress-relief annealing does not involve major micro-structural transformations, whereas selective surface treatment (such as flame and induction surface hardening) does involve microstructural transformations, but only in selectively controlled parts of the casting

Austenitizing Ductile Cast Iron

The usual objective of austenitizing is to produce an austenitic matrix with as uniform carbon content as possible prior to thermal processing. For a typical hypereutectic ductile cast iron, an upper critical temperature must be exceeded so that the austenitizing temperature is in two-phase (austenite and graphite) field. This temperature varies with alloy content.

The "equilibrium" austenite carbon content in equilibrium with graphite increases with an increase in austenitizing temperature. This ability to select (within limits) the matrix austenite carbon content makes austenitizing temperature control important in processes that depend on carbon in the matrix to drive a reaction. This is particularly true in structures to be austempered, in which the hardenability (or austemperability) depends to a significant degree on matrix carbon content. In general, alloy content, the original microstructure, and the section size determine the time required for austenitizing.

Annealing Ductile Cast Iron

When maximum ductility and good machinability are desired and high strength is not required, ductile iron castings are generally given a full ferritizing anneal. The microstructure is thus converted to ferrite, and the excess carbon is deposited on the existing nodules. Amounts of manganese, phosphorus, and alloying elements such as chromium and molybdenum should be as low as possible if superior machinability is desired because these elements retard the annealing process.

Recommended practice for annealing ductile iron castings is given below for different alloy contents and for castings with and without eutectic carbides:

- Full anneal for unalloyed 2 to 3% Si iron with no eutectic carbide: Heat and hold at 870 to 900°C (1600 to 1650°F) for 1 h per inch of section. Furnace cool at 55°C/h (100°F/h) to 345°C (650°F). Air cool.

- Full anneal with carbides present: Heat and hold at 900 to 925°C (1650 to 1700°F) for 2 h minimum, longer for heavier sections. Furnace cool at 110°C/h (200°F/h) to 700°C (1300°F). Hold 2 h at 700°C (1300°F). Furnace cool at 55°C/h (100°F/h) to 345°C (650°F). Air cool.

- Subcritical anneal to convert pearlite to ferrite: Heat and hold at 705 to 720°C (1300 to 1330°F), 1 h per inch of section. Furnace cool at 55°C/h (100°F/h) to 345°C (650°F). Air cool. When alloys are present, controlled cooling times through the critical temperature range down to 400°C (750°F) must be reduced to below 55°C/h (100°F/h).

Normalizing Ductile Cast Iron

Normalizing (air cooling following austenitizing) can result in a considerable improvement in tensile strength and may be used in the production of ductile iron of ASTM type 100-70-03.

The microstructure obtained by normalizing depends on the composition of the castings and the cooling rate. The composition of the casting dictates its hardenability that is, the relative position of the fields in the time-temperature CCT diagram. The cooling rate depends on the mass of the casting, but it also may be influenced by the temperature and movement of the surrounding air, during cooling.

Normalizing generally produces a homogeneous structure of fine pearlite, if the iron is not too high in silicon content and has at least a moderate manganese content (0.3 to 0.5% or higher). Heavier castings that require normalizing usually contain alloying elements such as nickel, molybdenum, and additional manganese, for higher hardenability to ensure the development of a fully pearlitic structure after normalizing. Lighter castings made of alloyed iron may be martensitic or may contain an acicular structure after normalizing.

The normalizing temperature is usually between 870 and 940°C (1600 and 1725°F). The standard time at temperature of 1 h per inch of section thickness or 1 h minimum is usually satisfactory. Longer times may be required for alloys containing elements that retard carbon diffusion in the austenite.

Quenching and Tempering Ductile Cast Iron

An austenitizing temperature of 845 to 925°C (1550 to 1700°F) is normally used for austenitizing commercial castings prior to quenching and tempering. Oil is preferred as a quenching medium to minimize stresses and quench cracking, but water or brine may be used for simple shapes. Complicated castings may have to be oil quenched at 80 to 100°C (180 to 210°F) to avoid cracks.

The influence of the austenitizing temperature on the hardness of water-quenched cubes of ductile iron shows that the highest range of hardness (55 to 57 HRC) was obtained with austenitizing temperatures between 845 and 870°C (1550 and 1600°F). At temperatures above 870°C, the higher matrix carbon content resulted in a greater percentage of retained austenite and therefore a lower hardness.

Castings should be tempered immediately after quenching to relieve quenching stresses. Tempered hardness depends on as-quenched hardness level, alloy content, and tempering temperature, as well as time. Tempering in the range from 425 to 600°C (800 to 1100°F) results in a decrease in hardness, the magnitude of which depends upon alloy content, initial hardness, and time.

Austempering Ductile Cast Iron

When optimum strength and ductility are required, the heat treater has the opportunity to produce an austempered structure of austenite and ferrite. The austempered matrix is responsible for a significantly better tensile strength-to-ductility ratio than is possible with any other grade of ductile cast iron. The production of these desirable properties requires careful attention to section size and the time-temperature exposure during austenitizing and austempering. times vary from 1 to 4 h.

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.

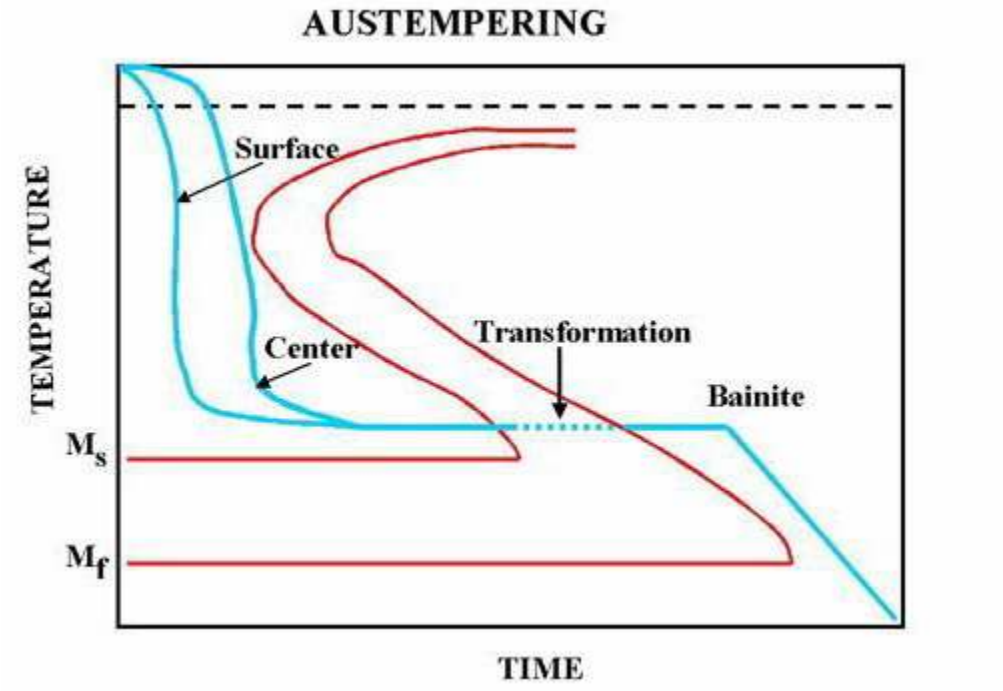


Fig. 4.1 Schematic diagram for austempering superimposed on TTT diagram

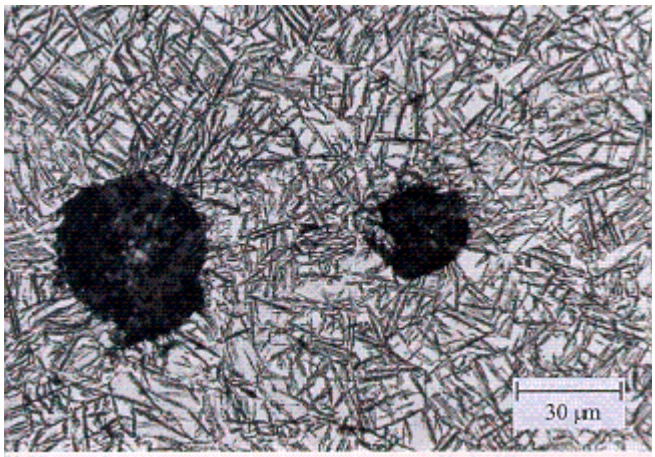


Fig 4.2 **Microstructure of austempered, ductile cast-iron. Retained austenite (light background), bainitic ferrite (dark shaves) and nodules of graphite**.

EXPERIMENTAL PROCEDURE

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 compatible to the machine specifications:

We got the sample from L&T Kansbal. The sample that we got was GGG-50 S.G Cast iron:→

Introduction of GGG-50 S.G Cast iron:→It is one of the German standard (DIN) specifications of the ductile iron having the pearlitic matrix (up to 70%) with relatively less amount of ferrite (30-40%). And so it has high hardness with moderate ductility and high strength as specified below. So we can also say that it is basically a pearlitic/ferritic ductile iron.

The sample that we got was cuboidal rod of length 130 mm and thickness of around 40 mm.

According to the ASTM standards for a specimen the ratio of gauge diameter to gauge length should be 1:5.
Hence we went for a turning operation of the 14 samples that we got which we did in the central workshop.

After the turning operation, the cuboidal rod was converted to a tumbler shaped specimen of the following specifications:

1. Gauge length – 70 mm
2. Gauge diameter- 14 mm
3. Total length- 90 mm
4. Grip diameter- 20 mm

Next the sample was subjected to various heat treatment processes and was taken to a UTS machine for testing of various mechanical properties.

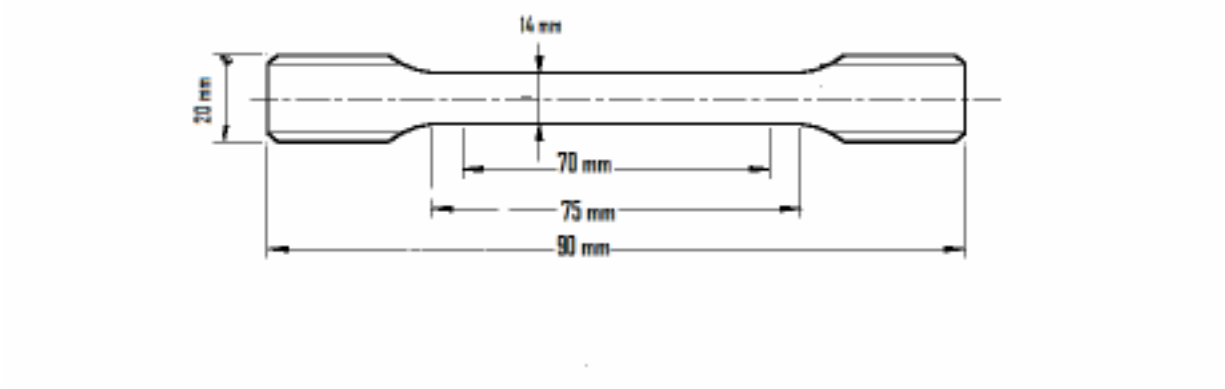


Fig. 5.1 Schematic diagram of tensile testing specimen

HEAT TREATMENT

Nodular cast irons (or ductile, or spheroidal graphite iron) are primarily heat treated to create matrix microstructures and associated mechanical properties not readily obtained in the as-cast condition. As-cast matrix microstructures usually consist of ferrite or pearlite or combinations of both, depending on cast section size and/or alloy composition.
The principle objective of the project is to carry out 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 900 deg Celsius
b) At 900 deg Celsius the specimen was held for 2 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 900 deg Celsius for 2 hrs is to homogenize the specimen. The temperature 900 deg Celsius 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 beginning the specimen was heated to the temperature of 900 deg Celsius
b) There the specimen was kept for 2 hour
c) Then the furnace was switched off and the specimen was taken out.
d) Now the specimen is allowed to cool in the ordinary 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 was performed to harden the 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 900 deg Celsius and were allowed to homogenize at that temp for 2 hour.
b) An oil bath was maintained at a constant temperature in which the specimen had to be put.
c) After 2 hour 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 release heat readily.

TEMPERING

This is the one of the important experiment carried out with the objective of the experiment being to induce some amount of softness in the material by heating to a moderate temperature range.
a) First the '9' specimen were heated to 900 deg Celsius for 2 hour and then quenched in the oil bath maintained at room temp.
b) Among the 9 specimen 3 were heated to 250 deg Celsius. But for different time period of 1 hour, 1and half hour and 2 hour respectively.
c) Now 3 more specimens were heated to 450 deg Celsius and for the time period of 1 hour, 1and a half hour and 2 hour respectively.
d) The remaining specimens were heated to 650 deg Celsius for same time interval of 1 hour. 1 and half and 2 hour respectively.
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 variety of properties within them.

AUSTEMPERING

This is the most important experiment 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 900 degree Celsius and sufficient time was allowed at that temperature, so that the specimen got properly homogenized.

b) A salt bath was prepared by taking 50% NaN03 and 50 % KnO3 salt mixture. The objective behind using NaNO3 and KNO3 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 Celsius. The salt remains in the liquid state in the temp range of 290-550 deg Celsius whereas the salt bath needed for the experiment should be at molten state at 350 deg Celsius

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 350d deg Celsius.

d) At that temp of 350 degree the specimen was held for 2 hrs

In this time the austenite gets converted to bainite. The objective behind choosing the temperature of 350 deg Celsius is that at this temperature will give upper bainite which has fine 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 UTS .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 Specimens are ready for the further experimentations

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 indenter 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 arbitrary hardness numbers. The dial contains 100 divisions. 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 a high hardness number. The hardness value thus obtained was converted into C scale b y using the standard converter chart.

HARDNESS TESTING

SPECIMEN SPECIFICATION	TIME	HARDNESS
Quenched from 900 and tempered at 250 degree celsius	1 hour	42
	1 ½ hour	37
	2 hour	33
Quenched from 900 and tempered At 450 degree celsius	1 hour	36
	1 ½ hour	32
	2 hour	28
Quenched from 900 and tempered at 650 degree Celsius	1 hour	31
	1 ½ hour	27
	2 hour	22
Austempered 350 degree celsius	1 hour	28
	2 hour	29
As Received	----------	21

Table 5.1, different hardness values in Rc scale for various heat treated s.g iron specimen

Specimen Specification	Time(in hours)	Hardness
Quenched from 900 and tempered at 250 degree celsius	1 hour	42
Quenched from 900 and tempered At 450 degree celsius	1 hour	36
Quenched from 900 and tempered at 650 degree celsius	1 hour	31

Table 5.2: Hardness vs. tempering temperature for constant tempering time of 1 hour

Specimen Specification	Time(in hours)	Hardness
Quenched from 900 and tempered at 250 degree celsius	1 ½ hour	37
Quenched from 900 and tempered At 450 degree celsius	1 ½ hour	32
Quenched from 900 and tempered at 650 degree celsius	1 ½ hour	27

Table 5.3: Hardness vs. tempering temperature for constant tempering time of 1 ½ hour

Specimen Specification	Time(in hours)	Hardness
Quenched from 900 and tempered at 250 degree celsius	2 hour	33
Quenched from 900 and tempered At 450 degree celsius	2 hour	28
Quenched from 900 and tempered at 650 degree celsius	2 hour	22

Table 5.4: Hardness vs. tempering temperature for constant tempering time of 2 hour

ULTIMATE TENSILE STRENGTH TESTING

The heat treated specimens were treated in UTS Machine for obtaining the % elongation, Ultimate Tensile Strength, yield Strength. The procedures for obtaining these values can be listed as follows;

1) at first the cross section area of the specimen was measured by means of an electronic slide caliper and then the gauge length was calculated.

2) Now the distance between the jaws of the UTS 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 150 KN.

5) The specimen was loaded till it fails

6) The corresponding Load vs. Displacement diagrams were plotted by using the software.

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

- % elongation = (change in gauge length of specimen/initial gauge length of the specimen.) *100

- Yield strength = load at 0.2% offset yield/ initial cross section area

- Ultimate tensile strength = maximum load/ initial cross section area

sample	Heat Treatment	Time(in hours)	Uts (in MPa)	Yield Strength(in MPa)	Elongation %
A	Quenched from 900 degree centigrade and tempered at 250 degree centigrade	1 hour	648	369	7.14
		1 ½ hour	647	368	9.42
		2 hour	570	322	18.714
B	Quenched from 900 degree centigrade and tempered at 450 degree centigrade	1 hour	599	342	12.57
		1 ½ hour	412	318	15.43
		2 hour	519	310	23.143
C	Quenched from 900 degree centigrade and tempered at 650 degree centigrade	1 hour	386	277	17.857
		1 ½ hour	384	261	21.84
		2 hour	383	265	23.857
D	Austempered , 350 degree centigrade	1 hour	911	388	16.86
		2 hour	936	407	17.142
E	Normalised	2 hour	610	360	6.46
F	Annealed	2 hour	376	243	23.92
G	As Received	……..	380	260	9.143

Table 5.5: Tensile properties of various heat treated S.G Cast iron specimens

Specimen specification	Time(in hours)	UTS(in Mpa)	Yield Strength(in Mpa)	Elongation%
Quenched from 900 and tempered at 250 degree centigrade	1	648	369	7.14
Quenched from 900 and tempered at 450 degree centigrade	1	599	342	12.57
Quenched from 900 and tempered at 650 degree centigrade	1	386	277	17.857

Table 5.6: Tensile properties for different tempering temperature for 1 hour tempering time

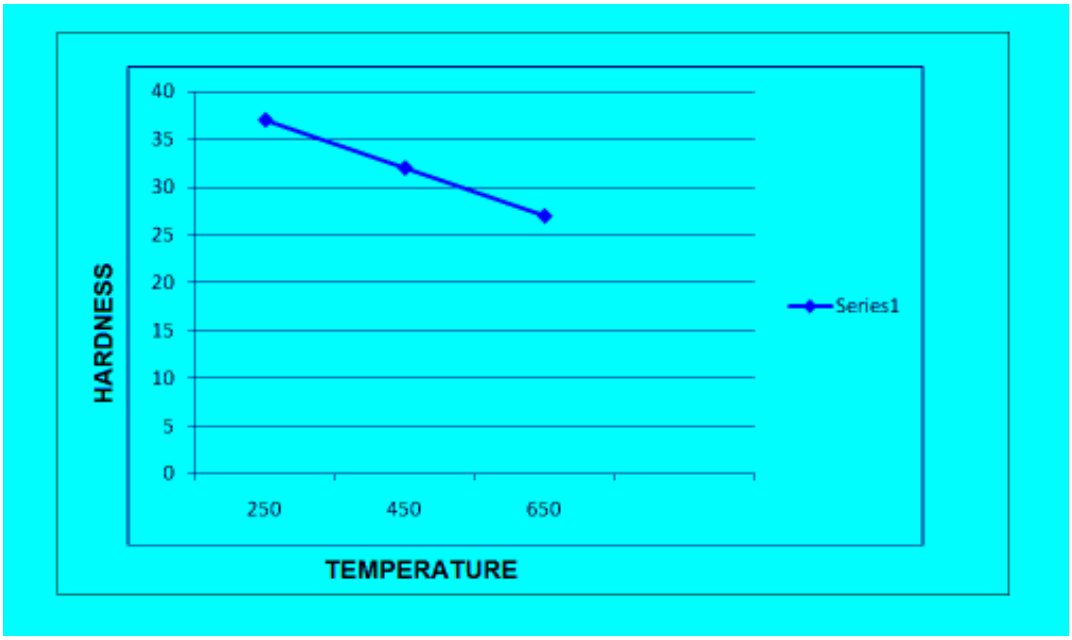
Specimen specification	Time(in hours)	UTS(in Mpa)	Yield Strength(in Mpa)	Elongation%
Quenched from 900 and tempered at 250 degree centigrade	1 ½	647	368	9.42
Quenched from 900 and tempered at 450 degree centigrade	1 ½	412	318	15.43
Quenched from 900 and tempered at 650 degree centigrade	1 ½	384	261	21.84

Table 5.7: Tensile properties for different tempering temperature for 1 ½ an hour tempering time

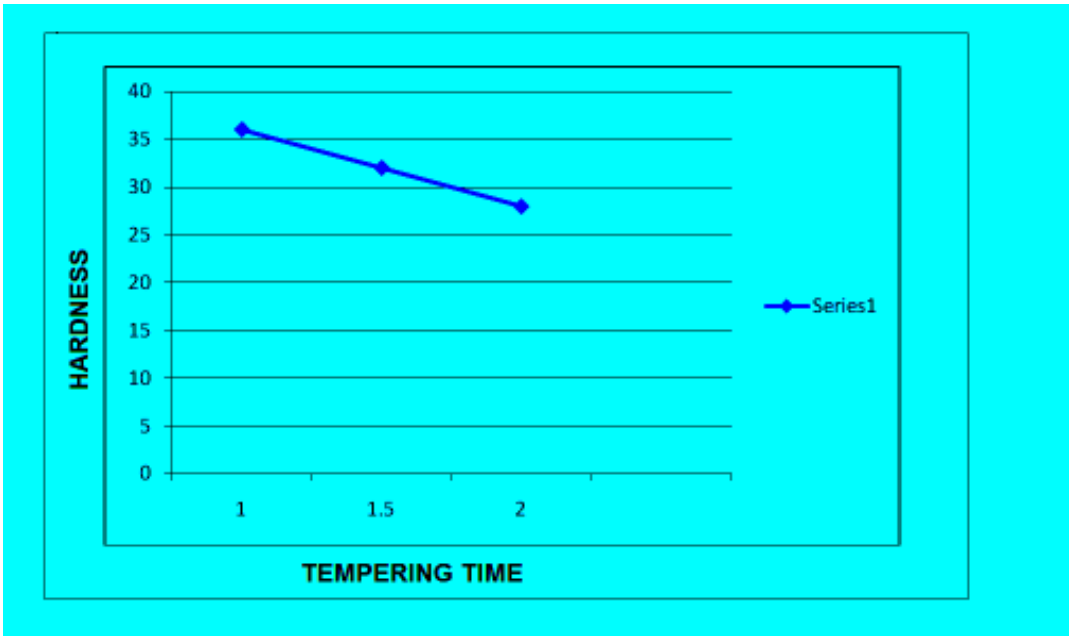
Specimen specification	Time(in hours)	UTS(in Mpa)	Yield Strength(in Mpa)	Elongation%
Quenched from 900 and tempered at 250 degree centigrade	2	570	322	18.714
Quenched from 900 and tempered at 450 degree centigrade	2	519	310	23.143
Quenched from 900 and tempered at 650 degree centigrade	2	383	265	23.857

Table 5.8: Tensile properties for different tempering temperature for 2 hour tempering time

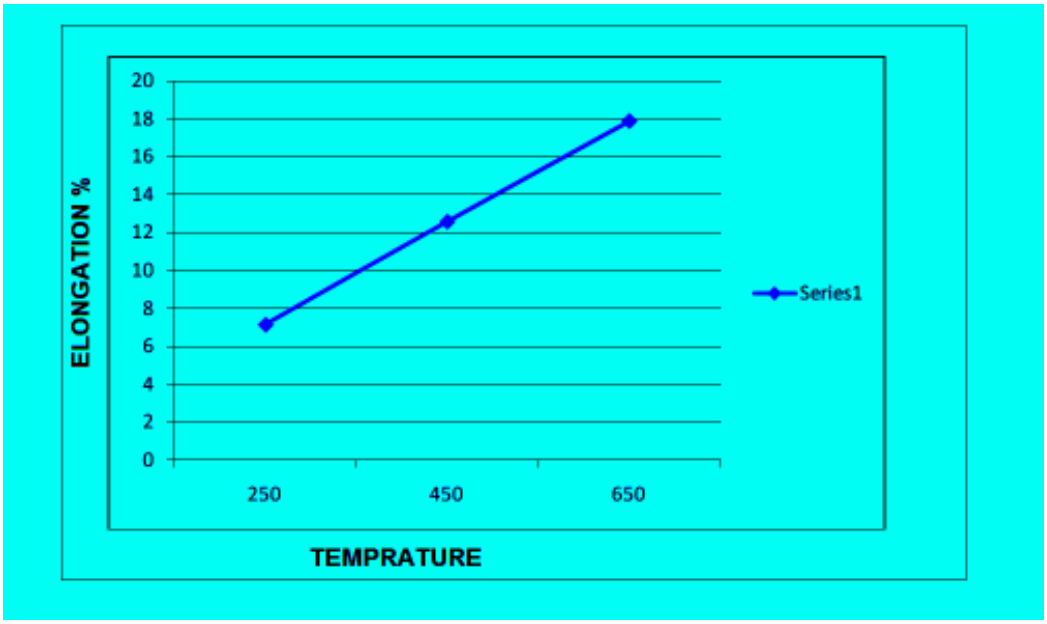
GRAPHS



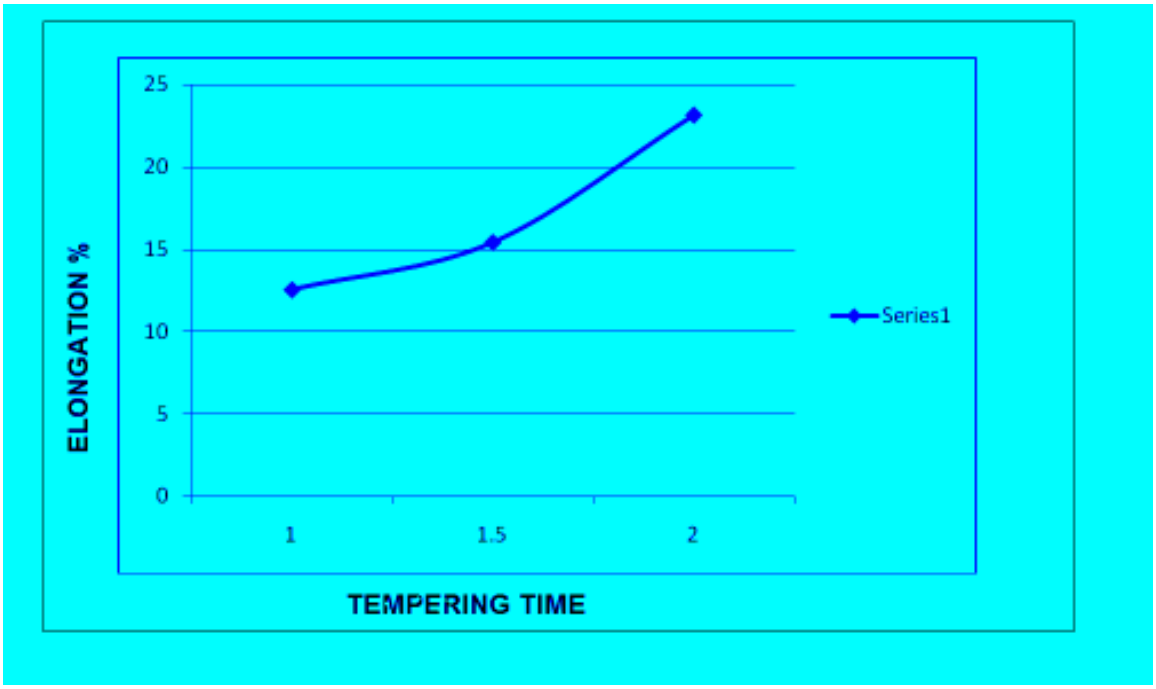
Hardness for different tempering temperature (in degree centigrade)



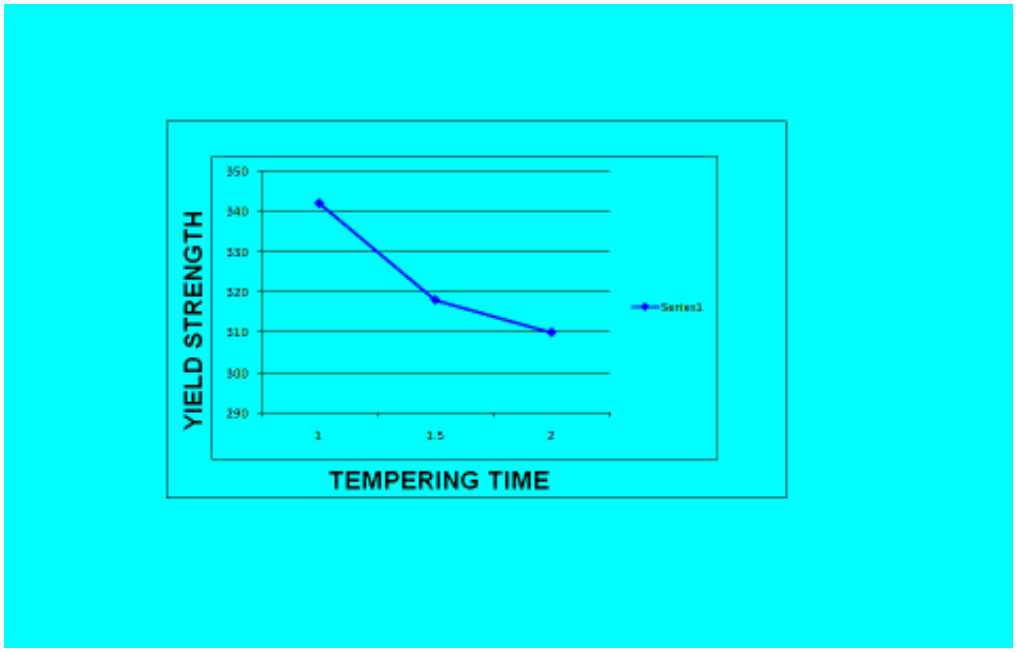
Variation in Hardness for different tempering time



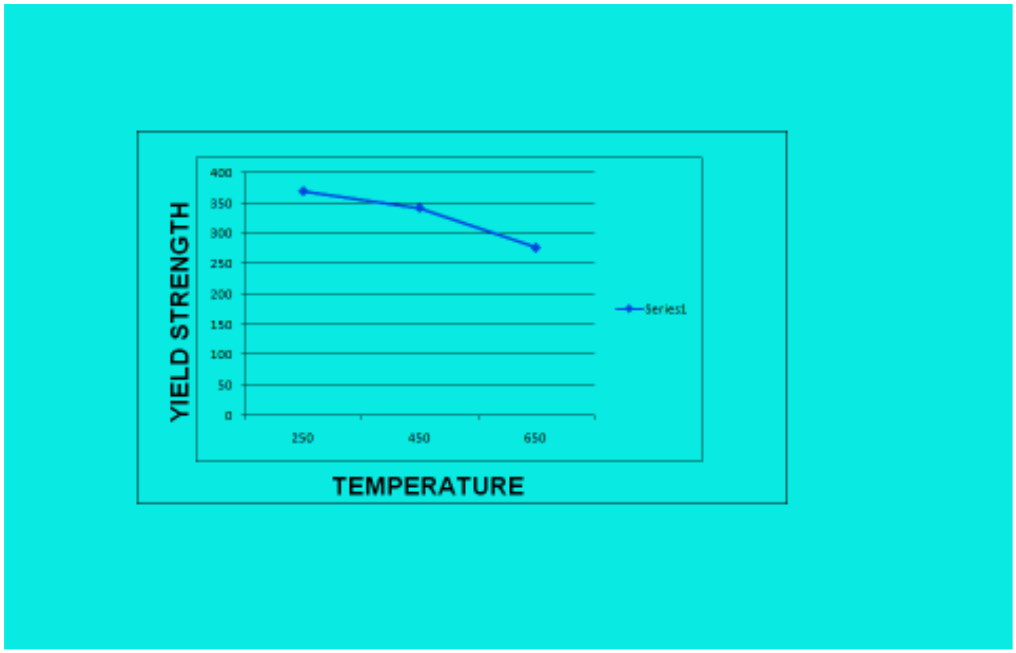
Variation of % elongation with different tempering temperature (in degree centigrade)



Variation of % elongation with different tempering time



Variation of yield strength with different tempering time



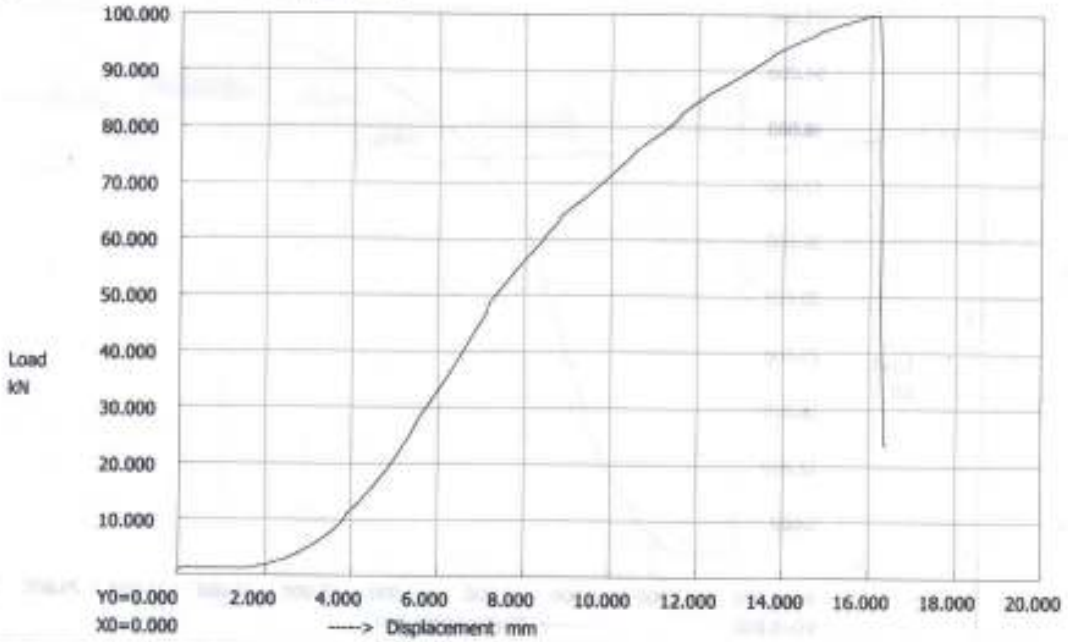
Variation of yield strength with tempering temperature (in degree centigrade)

Tempering at 250 degree Celsius and holding time 1 hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 50
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05102 (SL-39) , Record No. : 1 , Date of Test : 22/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 75 mm
Results of	: Tension Test
Peak Load (FMAX)	: 99.800 kN Elongation : 7.14 %
Disp. at FMAX	: 15.900 mm Yield Load : : 56.75kN
Breaking Load	: 23.750 kN Yield Stress : : .369kN/sq.mm
Max. Disp.	: 16.410 mm
Area	: 154.000 sq.mm
Ult. Stress	: 0.648 kN/sq.mm

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

Tempering at 250 degree Celsius and holding time 1 ½ hour

Test Certificate

Name of Company : LARSEN & TOUBRO LIMITED
Address : KANSBAHAL

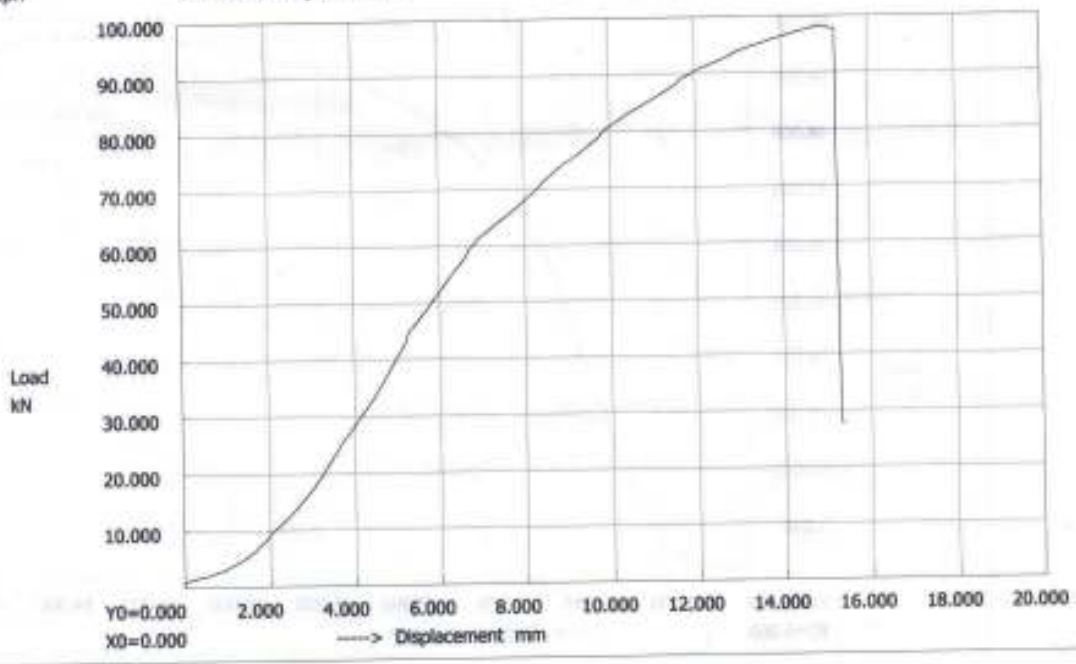
To : QA
Sample Identification : GGG 50

Machine : FIE Make Universal Testing Machine, UTE100-(SERVO)

Input Data : File Name : B05111 (SL-38), Record No. : 1, Date of Test : 19/04/2008
: Sample Type -- Round Solid Bar
: Diameter = 13.9 mm
: Initial Gauge Length : 70 mm Final Gauge Length : 76.6 mm

Results of : Tension Test
Peak Load (FMAX) : 98.250 kN
Disp. at FMAX : 14.910 mm
Breaking Load : 27.750 kN
Max. Disp. : 15.370 mm
Area : 151.808 sq.mm
Ult. Stress : 0.647 kN/sq.mm
Elongation : 9.42 %
Yield Load : : 55.65kN
Yield Stress : : .368kN/sq.mm

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

Tempering at 250 degree Celsius and holding time 2 hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 50
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05027(SL=32) , Record No. : 1 , Date of Test : 21/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 83.1 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 87.850 kN	Elongation	: 18.714 %
Disp. at FMAX	: 22.730 mm	Yield Load :	: 49.6 kN
Breaking Load	: 15.100 kN	Yield Stress :	: .322 kN/sq.mm
Max. Disp.	: 24.940 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.570 kN/sq.mm		

Graph : Load Vs Displacement

For LARSEN & TOUBRO LIMITED

Tempering at 450 degree Celsius and holding time 1 hour

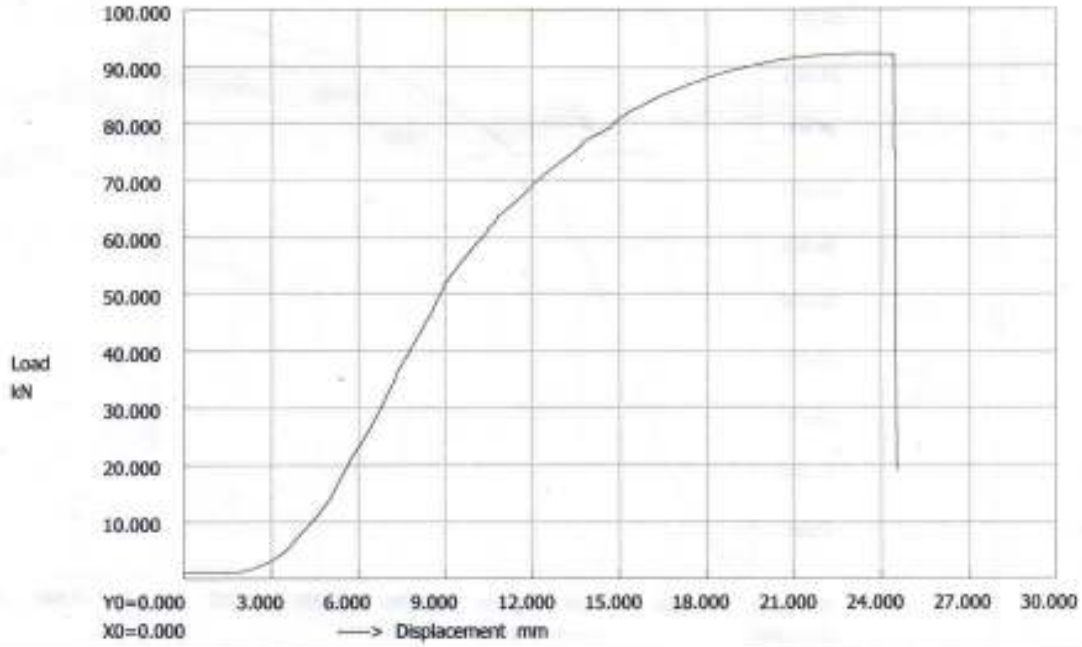
Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 50
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)

Input Data	: File Name : B05139 (SL–43) , Record No. : 1 , Date of Test : 19/04/2008
	: Sample Type – Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 78.8 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 92.200 kN	Elongation	: 12.57 %
Disp. at FMAX	: 23.190 mm	Yield Load :	: 52.6kN
Breaking Load	: 19.350 kN	Yield Stress :	: .342kN/sq.mm
Max. Disp.	: 24.620 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.599 kN/sq.mm		

Graph : Load Vs Displacement



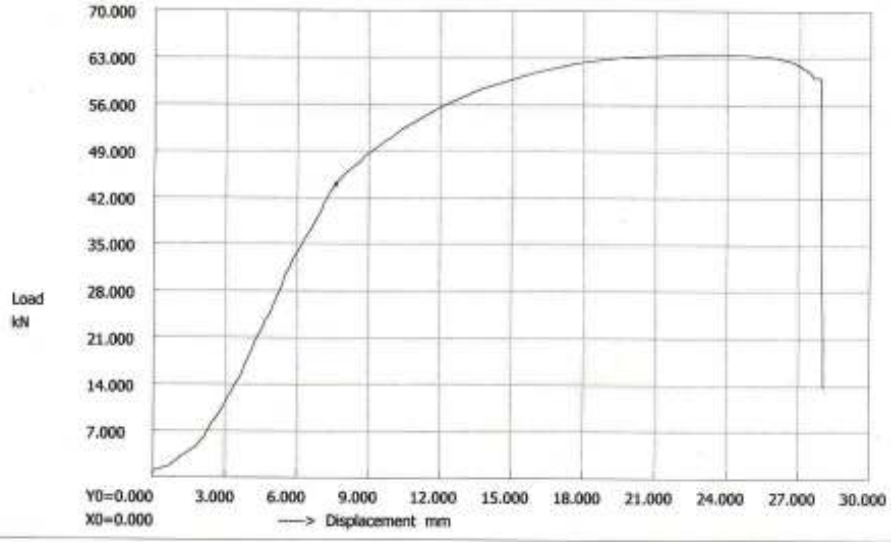
For LARSEN & TOUBRO LIMITED

Tempering at 450 degree Celsius and holding time 1 ½ hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: SG 400/15
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05200 , Record No. : 1 , Date of Test : 23/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 80.8 mm
Results of	: Tension Test
Peak Load (FMAX)	: 63.500 kN
Disp. at FMAX	: 22.440 mm
Breaking Load	: 13.750 kN
Max. Disp.	: 28.140 mm
Area	: 154.000 sq.mm
Ult. Stress	: 0.412 kN/sq.mm
Elongation	: 15.43 %
Yield Load :	: 48.97kN
Yield Stress :	: .318kN/sq.mm

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

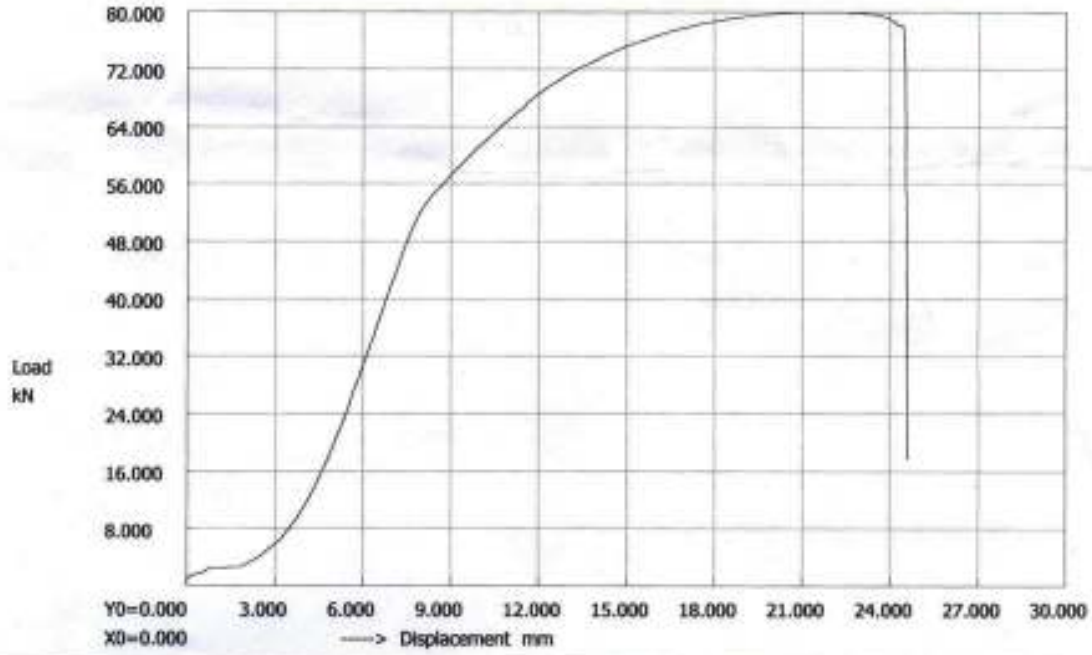
Tempering at 450 degree Celsius and holding time 2 hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	:
Sample Identification	: GGG 50
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B04927 (SL-23), Record No. : 1, Date of Test : 21/04/2008
	: Sample Type – Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 86.2 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 79.950 kN	Elongation	: 23.143 %
Disp. at FMAX	: 21.050 mm	Yield Load	: 47.7 kN
Breaking Load	: 17.800 kN	Yield Stress	: .310 kN/sq.mm
Max. Disp.	: 24.640 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.519 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

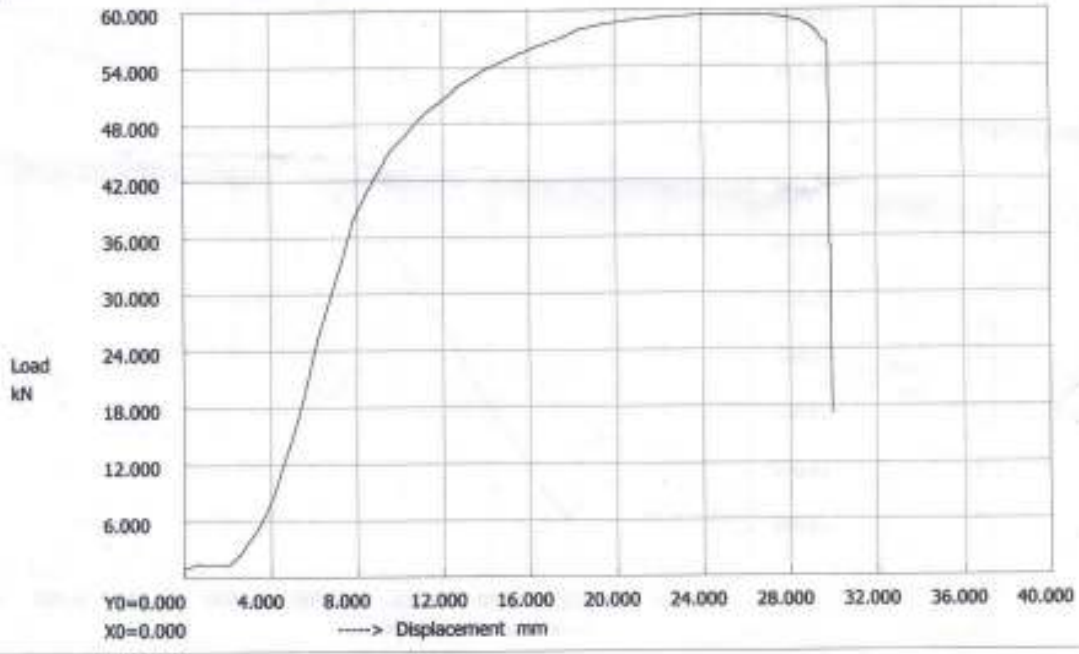
Tempering at 650 degree Celsius and holding time 1 hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 40.3
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05077 (SL--475) , Record No. : 1 , Date of Test : 22/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 82.5 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 59.500 kN	Elongation	: 17.857 %
Disp. at FMAX	: 25.430 mm	Yield Load :	: 42.65kN
Breaking Load	: 17.250 kN	Yield Stress :	: .277kN/sq.mm
Max. Disp.	: 30.020 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.386 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

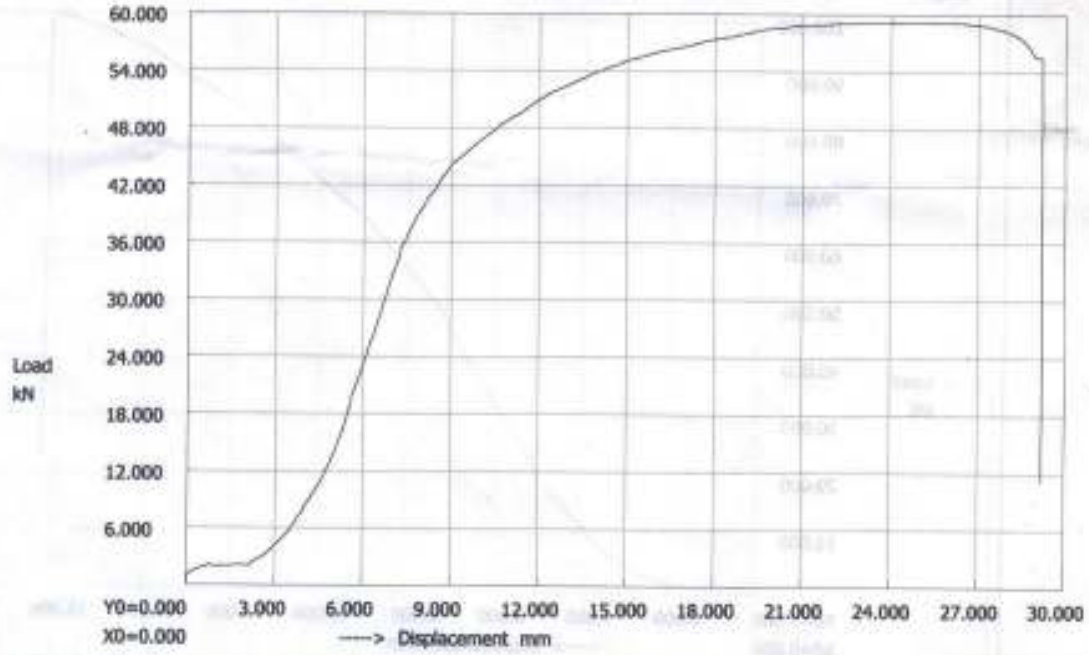
Tempering at 650 degree Celsius and holding time 1 ½ hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 40.3
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05101 (SL-572) , Record No. : 1 , Date of Test : 22/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 85.3 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 59.200 kN	Elongation	: 21.84 %
Disp. at FMAX	: 23.460 mm	Yield Load :	: 40.19kN
Breaking Load	: 11.150 kN	Yield Stress :	: .261kN/sq.mm
Max. Disp.	: 29.230 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.384 kN/sq.mm		

Graph : Load Vs Displacement



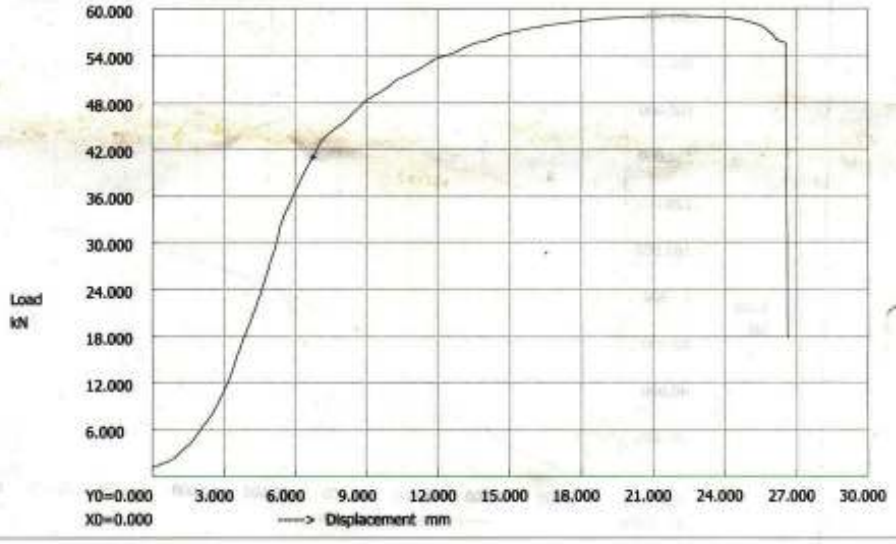
For LARSEN & TOUBRO LIMITED

Tempering at 650 degree Celsius and holding time 2 hour

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 40.3
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05195(SL-582) , Record No. : 1 , Date of Test : 23/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length: 86.7 mm
Results of	: Tension Test
Peak Load (FMAX)	: 59.050 kN
Disp. at FMAX	: 21.390 mm
Breaking Load	: 17.850 kN
Max. Disp.	: 26.700 mm
Area	: 154.000 sq.mm
Ult. Stress	: 0.383 kN/sq.mm
Elongation	: 23.857 %
Yield Load :	: 40.85kN
Yield Stress :	: .265kN/sq.mm

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

Austempered at 350 degree Celsius and holding time 1 hour

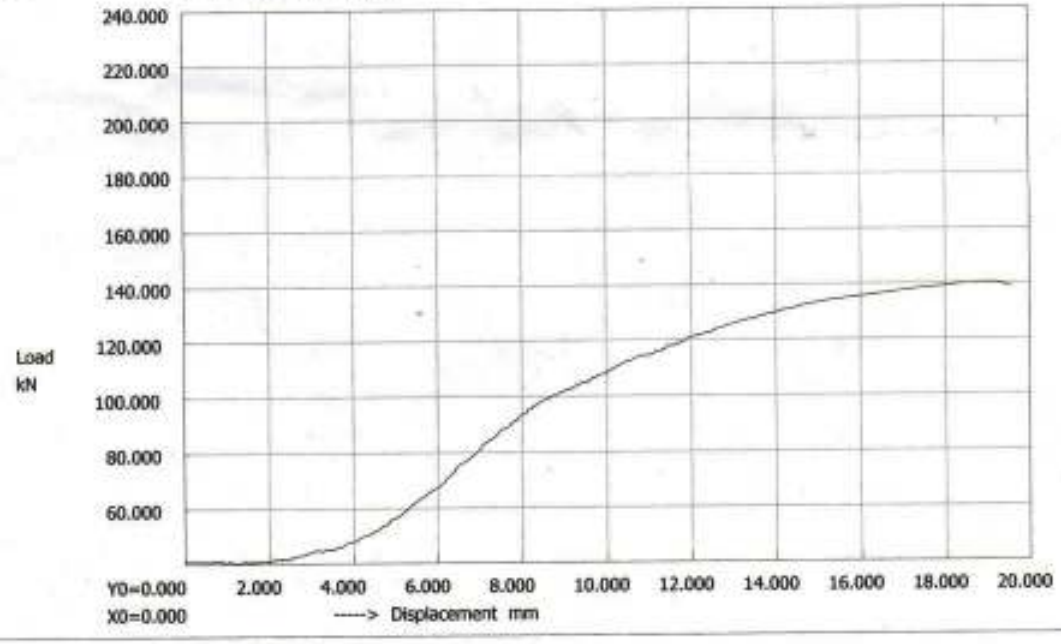
Name of Company : LARSEN & TOUBRO LIMITED
Address : KANSBAHAL
To : QA
Sample Identification : GG50
Machine : FIE Make Universal Testing Machine, UTE100-(SERVO)

Input Data : File Name : B05155 (SL-44&45) , Record No. : 1 , Date of Test : 23/04/2008
: Sample Type -- Round Solid Bar
: Diameter = 14 mm
: Initial Gauge Length : 70 mm Final Gauge Length : 81.8 mm

Results of : Tension Test

Peak Load (FMAX)	: 140.294 kN	Elongation	:16.86 %
Disp. at FMAX	: 19.000 mm	Yield Load :	: 59.7kN
Breaking Load	: 98.850 kN	Yield Stress :	: .388kN/sq.mm
Max. Disp.	: 19.550 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.911 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

Austempered at 350 degree Celsius and holding time 2 hour

Test Certificate

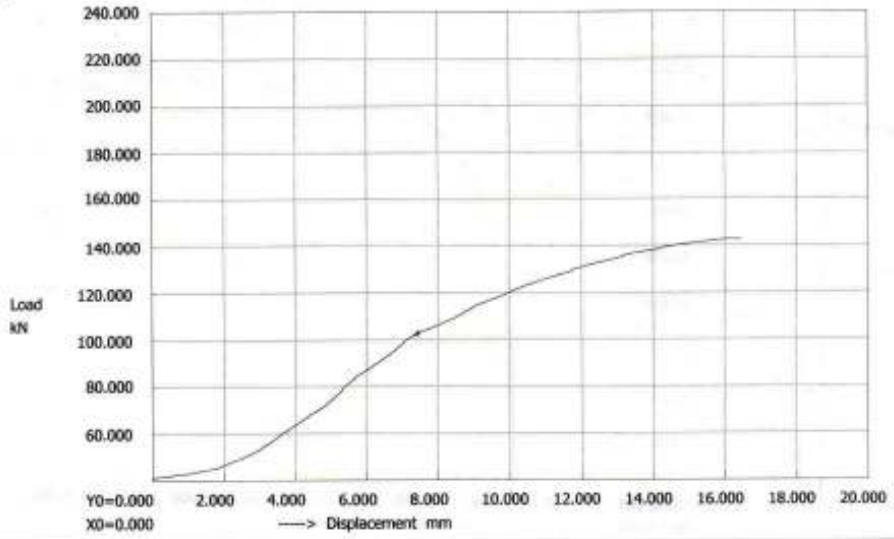
Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 50
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)

Input Data : File Name : B05204 (SL--49 & 51), Record No. : 1, Date of Test : 23/04/2008
: Sample Type -- Round Solid Bar
: Diameter = 14 mm
: Initial Gauge Length : 70 mm Final Gauge Length : 82 mm

Results of : Tension Test

Peak Load (FMAX)	: 144.144 kN	Elongation	: 17.142 %
Disp. at FMAX	: 16.440 mm	Yield Load :	: 62.65kN
Breaking Load	: 102.550 kN	Yield Stress :	: .407kN/sq.mm
Max. Disp.	: 16.440 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.936 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

Normalising at 900 degree Celsius and holding time 2 hour

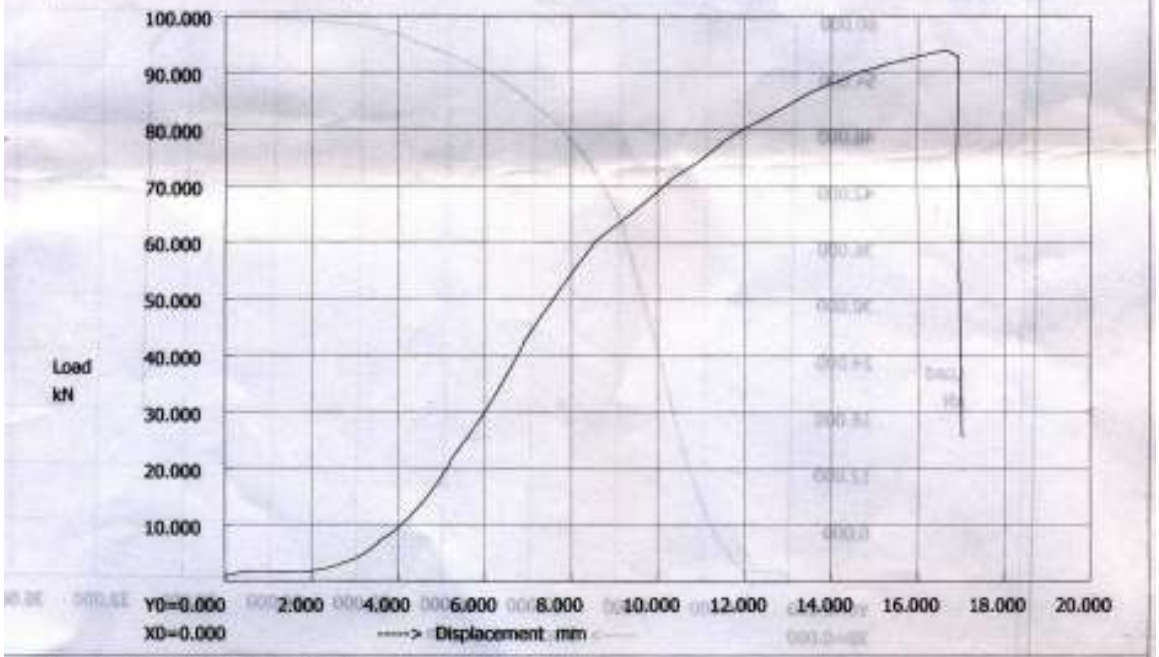
Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG50
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)

Input Data	: File Name : B05078 (SL-36), Record No. : 1 , Date of Test : 21/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 74.4 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 93.900 kN	Elongation	: 6.46 %
Disp. at FMAX	: 16.630 mm	Yield Load :	: 55.35kN
Breaking Load	: 25.750 kN	Yield Stress :	: .360kN/sq.mm
Max. Disp.	: 17.070 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.610 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

Annealing at 900 degree Celsius and holding time 2 hour

Test Certificate

Name of Company : LARSEN & TOUBRO LIMITED
Address : KANSBAHAL

To : QA

Sample Identification : GGG40.3

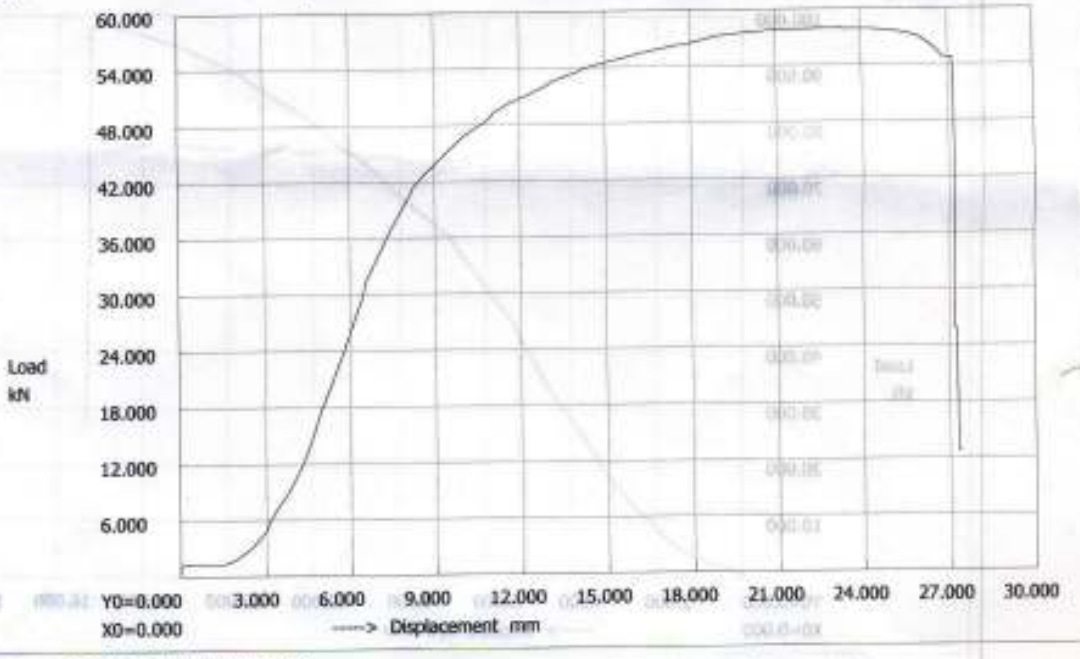
Machine : FIE Make Universal Testing Machine, UTE100-(SERVO)

Input Data : File Name : B05103 (SL-73) , Record No. : 1 , Date of Test : 19/04/2008
: Sample Type -- Round Solid Bar
: Diameter = 14 mm
: Initial Gauge Length : 70 mm Final Gauge Length : 86.7 mm

Results of : Tension Test

Peak Load (FMAX)	: 57.900 kN	Elongation	: 23.92 %
Disp. at FMAX	: 22.310 mm	Yield Load :	: 37.4kN
Breaking Load	: 12.750 kN	Yield Stress :	: .243kN/sq.mm
Max. Disp.	: 27.370 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.376 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

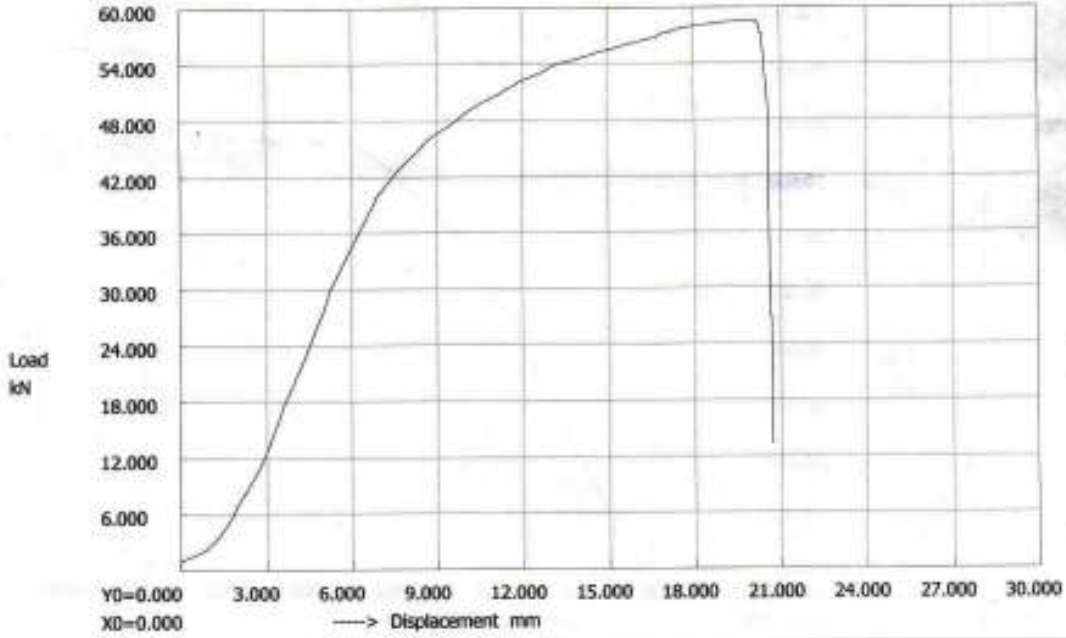
mechanical properties of as received sample

Test Certificate

Name of Company	: LARSEN & TOUBRO LIMITED
Address	: KANSBAHAL
To	: QA
Sample Identification	: GGG 40.3
Machine	: FIE Make Universal Testing Machine, UTE100-(SERVO)
Input Data	: File Name : B05141 (SL--576&78) , Record No. : 1 , Date of Test : 23/04/2008
	: Sample Type -- Round Solid Bar
	: Diameter = 14 mm
	: Initial Gauge Length : 70 mm Final Gauge Length : 76.4 mm

Results of	: Tension Test		
Peak Load (FMAX)	: 58.550 kN	Elongation	: 9.143 %
Disp. at FMAX	: 19.650 mm	Yield Load :	: 40.0kN
Breaking Load	: 13.350 kN	Yield Stress :	: .260kN/sq.mm
Max. Disp.	: 20.770 mm		
Area	: 154.000 sq.mm		
Ult. Stress	: 0.380 kN/sq.mm		

Graph : Load Vs Displacement



For LARSEN & TOUBRO LIMITED

DISCUSSION:

From the various experiments carried out following observations and inferences were made. It was seen that the various tensile properties followed a particular sequence:

HARDNESS

OBSERVATION 1

It can be observed from the figures obtained by plotting the hardness values vs. the tempering temperature that the hardness value of the specimen tempered at lowest temperature i.e. 250 degree centigrade is more as compared to that at 450 degree centigrade and even more than at 650 degree centigrade (which shows the lowest hardness value.)

INFERENCE 1

More is the tempering temperature, less is the hardness or more is the softness (ductility) induced in the quenched specimen.

OBSERVATION2

It can also be observed that keeping the tempering temperature same (either 250 degree or 450 degree or 650 degree), the hardness value decreases with the increase in tempering time. Infact hardness value is maximum for 1 hour and least for 2 hours.

INFERENCE2

More is the tempering time (keeping the tempering temperature constant), more is the ductility induced in the specimen.

Infact from the above two inferences it is quite clear that ductility increases with the increase in tempering temperature and also tempering time (Hence it is maximum for specimen tempered at 650 degree centigrade and tempered for 2 hours.)
On the other hand, hardness increases with the decrease in the tempering temperature and also with the decrease in tempering time (Hence the specimen tempered at 250 degree centigrade and tempered for 1 hour shows maximum hardness)

It can also be seen that the hardness value for the austempered specimen lies midway between that of the tempered specimen at 250 degree centigrade (for 1 hour) which is maximum and tempered specimen at 650 degree centigrade (for 2 hour) which is minimum. Infact its value is near to that obtained by tempering at 450 degree centigrade and tempered for 2 hours.

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If hardness is the only criteria than we should go for tempering at 250 degree centigrade (tempering time 1 hour). However an optimum combination of hardness and ductility is desired, we should go for austempered specimen.

TENSILE PROPERTIES

OBSERVATION-3

It can be observed from the table-(5.5) that for a particular tempering temperature with increase in tempering time the UTS gradually decreases and the same thing happens to the yield strength(except certain cases) and on the other hand elongation of the specimen increases which signifies that more ductility is induced with increase in tempering time.

INFERENCE-3

This clearly implies that the UTS and also to some extent the yield strength decreases with increase in tempering time where as the ductility(% elongation) increases

OBSERVATION-4

It can be seen that keeping the tempering time same but on increasing the tempering temperature (from 250 degree centigrade to 650 degree centigrade), the UTS value and the yield strength gradually decreases where as there is a gradual increase in % elongation.

INFERENCE-4

As a result of the above observation one can clearly infer that for a given tempering time, an increase in the tempering temperature decreases the UTS value and the yield strength of the specimen where as on the other hand increasing the % elongation and hence the ductility.

NOTE:-

From all the tempered specimen the specimen tempered to 650 degree centigrade for 2 hour has got maximum % elongation and hence maximum ductility has been induced, whereas for specimen tempered at 250 degree for 1 hour results in maximum strength.

It is seen that as a result of the special type of heat treatment given to the austempered specimen, the yield strength of the specimen is maximum among all the quenched, annealed and normalized specimen. The strength obtained is even more than the maximum strength obtained among all heat treated specimen i.e. tempered at 250 degree centigrade for 1 hour.

Thus it is quite clear that if an optimum combination of properties i.e. UTS, Yield Strength, Hardness and ductility (% elongation) is desired, austempering of the S.G cast iron is the one that we should go for.

CONCLUSION

From the various results obtained during the project work it can be concluded that the mechanical properties vary depending upon the various heat treatment processes. Hence depending upon the properties and applications required we should go for a suitable heat treatment processes.

When ductility is the only criteria tempering at high temperature for 2 hours gives the best result among all tempering experiments however it is simply the hardness of the S.G Cast iron that is desired than we should go for low temperature tempering for 1 hour or so. However if strength is also desired along with hardness, this should not be done. It is seen that annealing causes a tremendous increase in % elongation (ductility).

It can be clearly seen comparing all the heat treatment processes, optimum combination of UTS, Yield Strength, % Elongation as well as hardness can be obtained through austempering only.

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