“ EFFECT OF AUSTEMPERING BEHAVIOUR OF DUCTILE IRON”

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Cast iron

- Cast irons are alloys of iron, carbon, and silicon in which more carbon is present than can be retained in solid solution in austenite at the eutectic temperature. In gray cast iron, the carbon that exceeds the solubility in austenite precipitates as flake graphite.

- Gray irons usually contain 2.5 to 4% **C**, 1 to 3% **Si**, and additions of manganese, depending on the desired microstructure (as low as 0.1% **Mn** in ferritic gray irons and as high as 1.2% in pearlitics). Sulphur and phosphorus are also present in small amounts as residual impurities.

Ductile cast iron and its properties

- **History of Ductile Iron**

Foundry men continued to search for an ideal cast iron an as cast “grey iron” with mechanical properties equal or superior to malleable iron.

In 1943, Keith Dwight Mills made a ladle addition of Magnesium (as copper-magnesium alloy) to cast iron in the International Nickel Company Research Laboratory. The solidified castings contained no flakes but nearly perfect spheres of graphite.

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- Five years later, at 1948 AFS Convention, Henton Morrogh of British Cast Iron Research Association announced the successful production of spheroidal graphite in hyper eutectic grey iron by addition of small amount of cerium.

- At the same time Morrogh from the International Nickel Company, presented a paper which revealed the development of magnesium as graphite spheroidizer.

- On October 25, 1949, patent 2,486,760 was granted to the International Nickel Company, assigned to Keith D. Mills , Albert P. Gegnebin and Norman B. Pilling. This was the official birth of ductile iron.

Various grade of S.G. irons

Grade	Tensile Strength (N/mm2)	Hardness (BHN)	Elongation (%)
800-2	800	245-335	2
700-2	700	225-305	2
600-3	600	190-270	3
500-7	500	170-230	7
450-10	450	160-210	10
400-15	400	130-180	15
400-18	400	130-180	18

Family of Ductile Irons

With a high percentage of graphite nodules present in the structure, mechanical properties are determined by the ductile iron matrix. The importance of matrix in controlling mechanical properties is emphasized by the use of matrix names to designate the following types of ductile iron.

- Austenitic Ductile Iron.
- Ferritic Ductile Iron.
- Ferritic Pearlitic Ductile Iron.
- Pearlitic Ductile Iron.
- Martensitic Ductile Iron.
- Bainitic Ductile Iron.

Production of Ductile Iron

- Ductile iron can be produced by treating low sulphur liquid cast iron with an additive usually containing magnesium and then inoculated just before or during casting with a silicon-containing alloy.

Raw Material

- To produce ductile iron with the best combination of strength and toughness, raw materials must be chosen which have lower than 0.02 wt.% sulphur and are low in trace elements. Low manganese content is also needed to achieve as-cast ductility. Higher strength grades of ductile iron can also be made with common grades of constructional steel scrap, pig iron and foundry returns, but certain trace elements e.g. lead, antimony and titanium are usually kept as low as possible to achieve good graphite structure.

Charge Materials

- The metallic charge for ductile iron base consists mainly of: Pig iron, steel scrap, return ductile iron scrap and ferroalloys.

Pig Iron

- The ideal pig iron for ductile iron charge is pure iron- carbon alloy, which is not available. It is believed that sorel metal is the best charge. In sorel metal the manganese content is very low i.e. 0.009 wt.% and its content of elements which either promote carbides or interfere with spheroidization of graphite is low.

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Steel Scrap

- Steel scrap is an important component of ductile iron charge. Chemical composition and physical shape are to be considered. The physical shape includes dimensions and specific surface. All melting equipment has its limitations as to maximum size. The cupola furnace also has a minimum size limitation.
- Even though very small pieces may be charged into electric induction or arc furnaces (such as thin plate chippings) these have very large specific surface areas which rust rapidly. Even though rust is not believed to cause metallurgical deterioration, it certainly increases slag quantity, acidity and corrosiveness. Whenever possible, such scrap should be used in a balanced condition.
- Despite these difficulties, steel scrap will remain in use because it is normally less expensive than pig iron and also available in plentiful supply.

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Ductile Iron Scrap

- Only scrap of ductile iron of known quality should be used.

Ferro Alloys

- When Ferro alloys are needed in the charge, the chemical composition of the alloys should be known.

Desulphurization

- A variety of compounds are capable of removing sulphur from molten iron. Even manganese desulphurizes but it is an expensive material.

Spherodizing Treatment

- Magnesium is added to the bath to remove sulphur and oxygen and radically change the graphite growth morphology. Magnesium reacts with oxygen to form highly stable MgO which floats on the surface and can be skimmed off easily.

- Oxygen content thus reduces from typical levels of 90-135 ppm to about 15-35 ppm.

- Si is added for additional DE oxidation.

- After nodulising treatment inoculants like Mg have their Spherodizing effect on the graphite structure so that graphite nodules can be formed.

- Although various methods are employed for introducing magnesium into molten metal, the universally accepted procedure is the sandwich method.

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- The ladle should be filled as quickly as possible.
- This improves the magnesium recovery.
- The magnesium recovery depends on metal temperature, the quantity of metal treated and the design of the ladle.

Spherodizing Treatment Alloys

- There are two main alloys in use, nickel magnesium (NiMg) and ferro-silicon- magnesium (FSM). Ferro-silicon-magnesium alloy is commonly used. It should have the composition shown in table.

Mg %	Si %	Ca %	Ce %	Fe %
4-6	45-50	1 max	0.5	balance

Amount of Magnesium Required

- The amount of magnesium alloy required depends on two factors:

  (a) The temperature of metal, the higher the temperature, the lower the recovery of magnesium.

  (b) Sulphur content of the base iron to be treated; the higher the sulphur content, the greater is the amount of magnesium to be added.

- **Calculation of Magnesium:**

  Different formulas are used to calculate the amount of magnesium required. The commonly used formula is

$$\text{Mg to add (\%)} = \frac{\text{Mg} - \text{content required \%}}{\text{Mg recovery \%} \times 0.01} + \text{Base S\%}$$

Heat Treatment

- To fully utilize the range of properties beyond the limits of those produced in as-cast condition. Heat treatment is a very valuable tool.

- The heat treatments can be carried out on Spheroidal Graphite Iron to achieve the following:
  - Increase toughness and ductility.
  - Increase strength and wear resistance.
  - Increase corrosion resistance.
  - Stabilize the microstructure, to minimize growth.
  - Equalize properties in castings with widely varying section sizes.
  - Improve consistency of properties.
  - Improve machinability and Relieve internal stresses.

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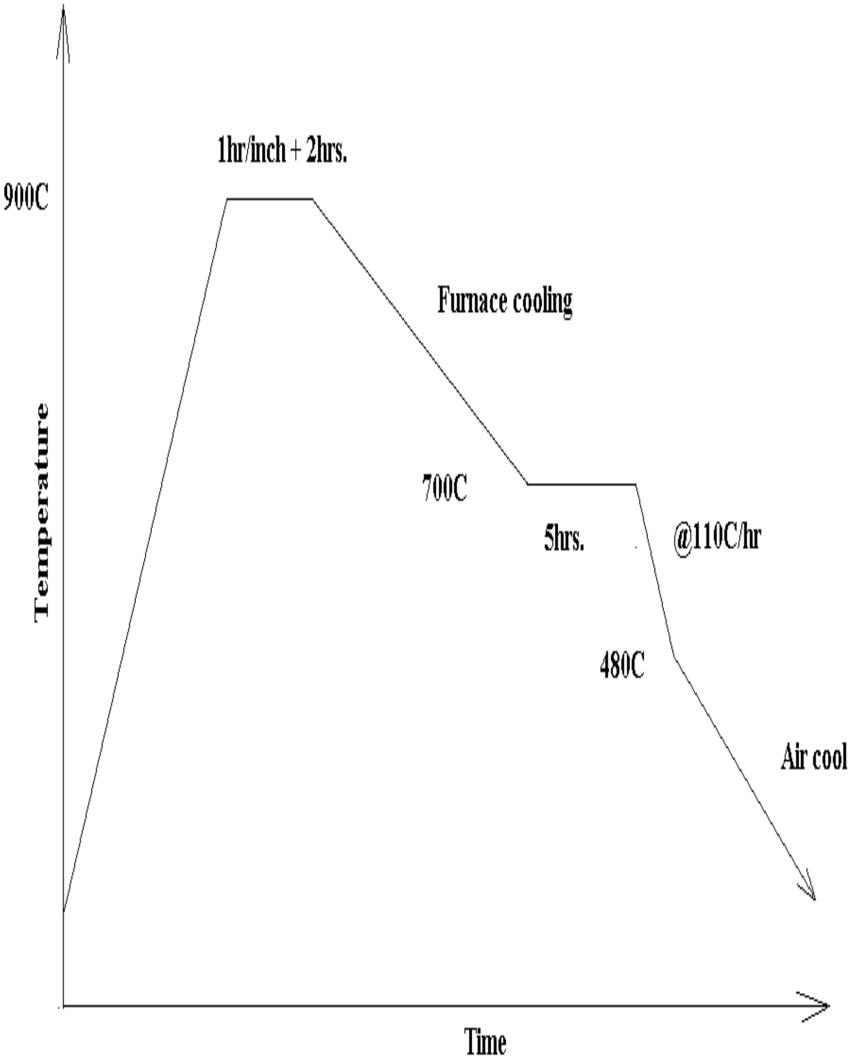
- The most important heat treatments and their purposes are:
  - Stress relieving, a low-temperature treatment, to reduce or relieve internal stresses remaining after casting.
  - Annealing, to improve ductility and toughness, to reduce hardness, and to remove carbides.
  - Normalizing, to improve strength with some ductility.
  - Hardening and tempering, to increase hardness or to improve strength and raise proof stress ratio.
  - Austempering, to yield a microstructure of high strength, with some ductility and good wear resistance.
  - Surface hardening, by induction, flame, or laser, to produce a locally selected wear-resistant hard surface.

Annealing

Annealing, sometimes referred to as full annealing, is necessary for castings which are carbidic as – cast. The samples are hold at a temperature of 900 ºC for 2hours and one additional hour per inch section thickness. Then, cool to 700 ºC and hold there for 5 hrs. Finally, cool at a maximum rate of 110 ºC per hour to 480 ºC, then air cool.

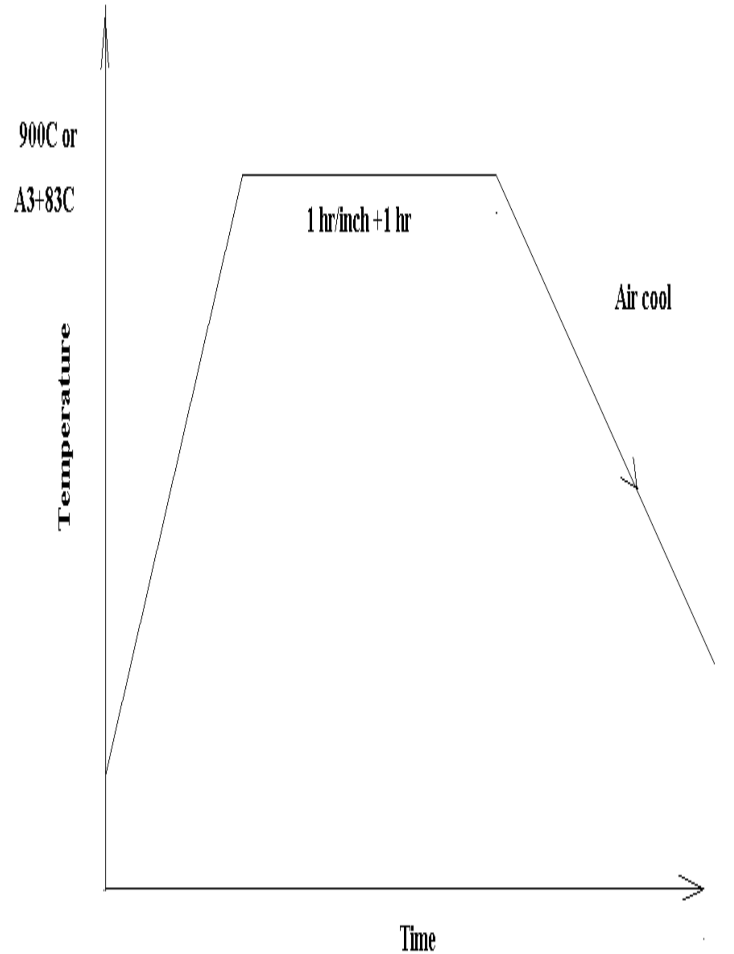


Annealing heat treatment

Normalizing

- The result of normalizing is a fine pearlite matrix. Heat the casting to 900 ºC, if massive carbides are present in the structure. Otherwise, heat to A3 +83 ºC. Then, hold for one hour plus one additional hour per inch section thickness. Remove the casting from the furnace and air cool. Most ductile irons to be normalized are also alloyed with up to 1.5% Cu or up to 0.075% Sn in order to promote a fully pearlitic matrix. The heavier the section the more alloying is needed. To increase hardness and strength Cu is mixed.

- When Si content is more than 2.5%, the casting should be fast cooled to get a fully pearlitic matrix.



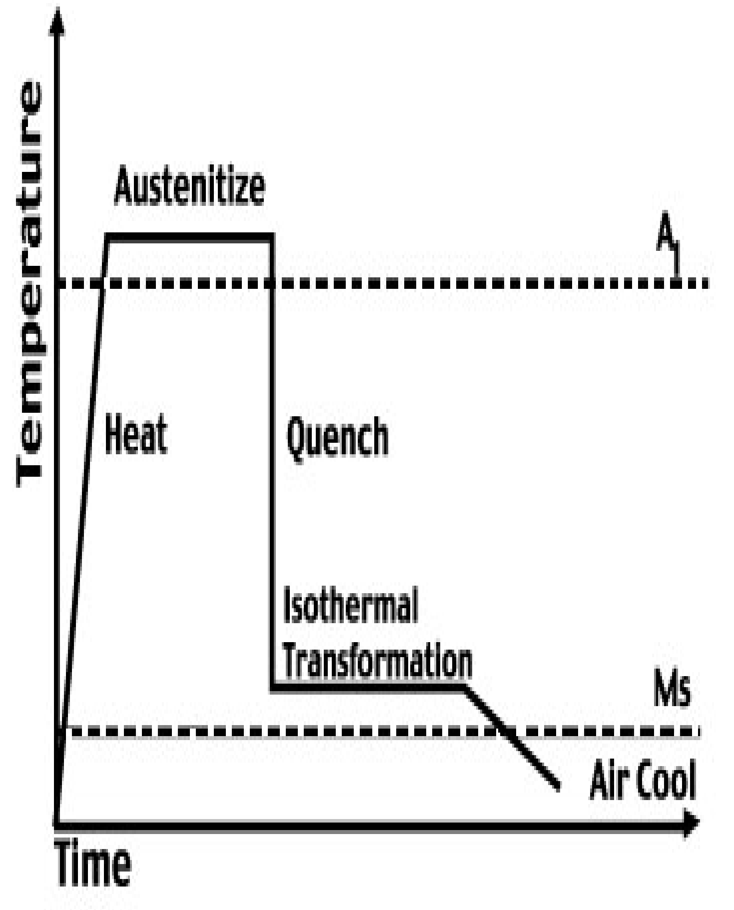
Normalizing Treatment

Austempering Process

- **Austempered ductile iron** is produced by heat-treating cast ductile iron to which small amounts of nickel, molybdenum, or copper have been added to improve hardenability. Specific properties are determined by the careful choice of heat treating parameters. Austempering involves the nucleation and growth of acicular ferrite within austenite, where carbon is rejected into the austenite. The resulting microstructure of acicular ferrite in carbon-enriched austenite is called ausferrite. Even though austenite in austempered ductile iron is thermodynamically stable, it can undergo strain-induced transformation to martensite when locally stressed. The result is islands of hard martensite that enhance wear properties.Advanced Cast Products uses salt baths for austenitizing, quenching, and austempering in order to achieve close dimensional control. Times and temperatures are tightly controlled.

Steps in Austempering Process

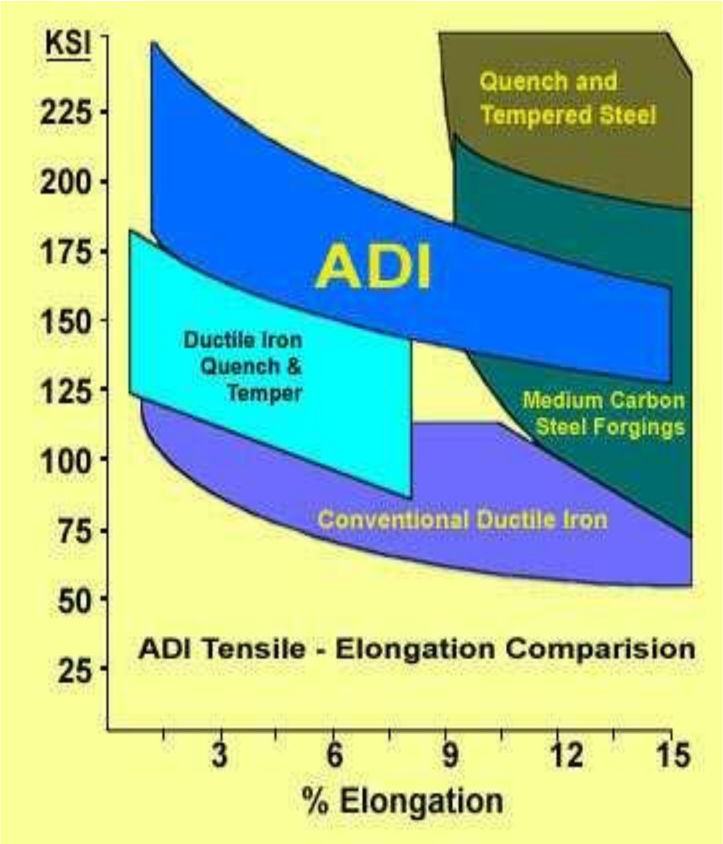
1. Heat castings in a molten salt bath to austenitizing temperature.
2. Hold at austenitizing temperature to dissolve carbon in austenite.
3. Quench quickly to avoid pearlite.
4. Hold at austempering temperature in molten salt bath for isothermal transformation to ausferrite.



Austempering Procedure

Properties of ADI Compared to Steel

- ADI is much easier to cast than steel.
- ADI is approximately 9% lighter than steel.
- ADI has minimal draft requirements compared with steel forgings ADI loses less of its toughness than steel at sub-zero temperatures ADI work hardens when stressed.
- ADI has more damping capacity than steel.



Comparison of ADI’S Mechanical properties with other treated irons

ADI Microstructure

- Ductile Cast Iron undergoes a remarkable transformation when subjected to the austempering heat process. A new microstructure (ADI) results with capability superior to many traditional, high performance, ferrous and aluminium alloys. To optimise ADI properties for a particular application the austempering parameters must be carefully selected and controlled. Castings are first austenitised to dissolve carbon, then quenched rapidly to the austempering temperature to avoid the formation of deleterious pearlite or martensite. While the casting is held at the austempering temperature nucleation and growth of acicular ferrite occurs, accompanied by rejection of carbon into the austenite. The resulting microstructure, known as "Ausferrite", gives ADI its special attributes. Ausferrite exhibits twice the strength for a given level of ductility compared to the pearlitic, ferritic or martensitic structures formed by conventional heat treatments.

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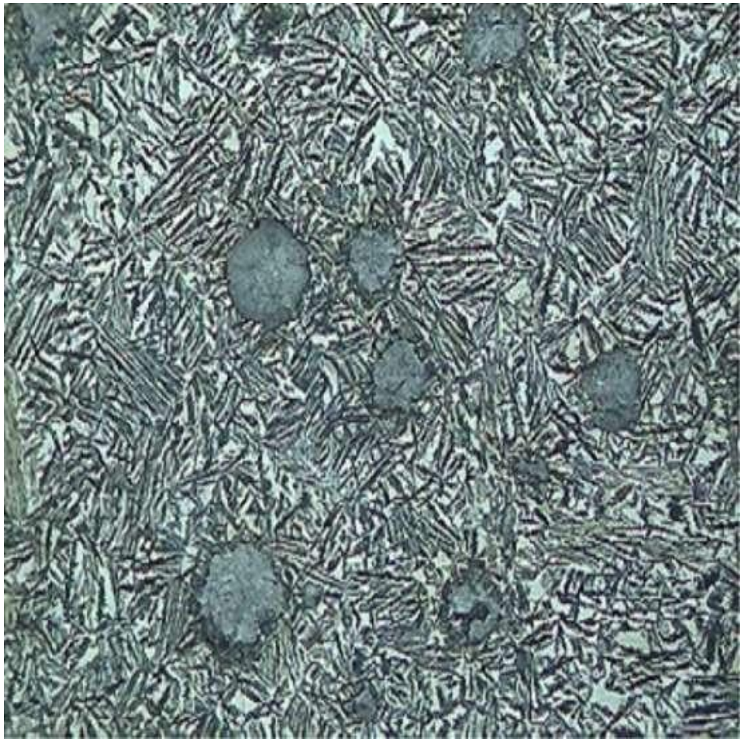
- Because the carbon rich austenite phase is stable in Austempered Ductile Iron it enhances the bulk properties. Furthermore, while the austenite is thermodynamically stable, it can undergo a strain-induced transformation when locally stressed, producing islands of hard martensite that enhance wear properties. This behaviour contrasts with that of the metastable austenite retained in steels, which can transform to brittle martensite.



Microstructure of ADI

Applications Of ADI

Over twenty years, heat treatment specialists and equipment engineers have refined the Austempering process and plant to enable reliable production of high grade Austempered materials.

Application of ADI in different areas.

Literature Review

- **Susanta Kumar Swain and Sudipta Sen** [2012] have investigated on effect of austempering variables on the mechanical properties of spheroidal graphite iron. Austempering variables such as time and temperature have been taken in to consideration for the present investigation with respect to tensile properties and characterization of graphite morphology. Two types of spheroidal graphite (SG) cast iron samples with different weight percentage of copper were austempered at four different temperatures. The austempering temperatures were 250˚C, 300˚C, 350˚C and 400˚C.The influence of austempering process on the mechanical properties of spheroidal graphite iron was investigated as a function of austempering time and temperature. The cooling rate and the quenching technique adopted play an important role for the property development of spheroidal graphite iron. The tensile properties have been correlated with the graphite morphology for both the grades of ADI. SEM micrographs have been taken from the fractured surface of the tensile specimens under different austempering conditions.

- It has been found from the result that ADI having the alloying element (Cu), achieved significant mechanical properties as compared to other grade (M1) throughout the different austempering process adopted in this study.

- **Prof .P.M.Ingole et al.** [2012] have investigate effect of Basic Chemical Element in SGI The basic chemical element such as carbon, silicon, manganese, magnesium, copper etc. plays an important role in SGI (Spheroidal Graphite Iron) castings process. The behaviour of these elements in molten metal of the ductile iron plays a different role because of their different mechanical and chemical properties. If we govern such composition that will be optimal by virtue of its study of effects on castings. As we know, there is small change in the chemical composition, the wide effects on the mechanical properties and their microstructure. The chemical compositions in ductile iron are always considered in the range. So that it is difficult to achieve the targeted mechanical properties and the microstructure as per the given specification it always affects in the end use of the product.

- **Alan Vasko** [2012] has investigated on microstructure and mechanical properties of austempered Ductile iron. Results of the experiment show that in dependence on transformation temperature and holding time, various matrixes can be obtained (i.e. mixture of bainite with retained austenite), containing various content of retained austenite and consequently mechanical properties of ADI are changed. The tensile strength and Brinell hardness of the specimens after isothermal heat treatment are increased with decreasing temperature of isothermal transformation of austenite and the fatigue strength is decreased with decreasing temperature of isothermal transformation of austenite.

- **A Shayesteh-Zeraati et al.**[2010] have investigate on the effect of aluminum content on morphology, size, volume fraction, and number of graphite nodules in ductile cast iron. Addition of aluminum to ductile iron causes some fundamental changes in iron–carbon phase diagrams and, as a result, improves graphite formation during eutectic transformation. Results reveal that aluminum compounds have been formed in the core of graphite nodules; thus aluminum plays an important role in the formation of graphite nodules. Furthermore, it is indicated that an increase in the aluminum content also leads to an increase in the number of graphite nodules and a decrease in the nodule size. By using electron probe microanalysis, the segregation of aluminum and silicon between graphite nodules has been studied.

- **Chang-Yong Kang et al.** investigated the effects of austempering and subzero treatment on the damping capacity in ADI. The damping capacity of ADI was rapidly increased by the austempering treatment, although it was not affected by the austempering temperature or time. After subjecting the ADI to subzero treatment, the austenite was transformed into martensite, and the volume fraction of the martensite and damping capacity increased as the subzero treatment temperature decreased. The subzero treatment sharply increased the damping capacity of the ADI. By increasing the subzero treatment time, the damping capacity rapidly increased until the subzero treatment time reached 30 min, after which it increased gradually. By increasing the volume fraction of the martensite, the damping capacity was rapidly increased until the volume fraction was 5%, beyond which it increased gradually.

- **Hasan Avdusinovic, Almaida gigovic** [October, 2009] have investigated the effect of heat treatment of nodular cast iron. Possibility of thermal treatment is additional advantage of this material. Applying an adequate thermal treatment regime gives the superior characteristics to the nodular castings that are in many cases substitution for expensive steel parts and other materials. Improvements are primarily related to the improvement of mechanical and ductile properties of the castings due to developing of new metallic microstructure i.e. ausferrite with nodular graphite.

- **N. D. Prasanna et al.**[2009] have investigated effect of austempering heat treatment on mechanical properties and corrosion characteristics of IS 400/12 grade ductile iron. Corrosion tests were carried out to determine the weight loss and corrosion rate of specimens; using salt spray fog type apparatus. Corrosion test was carried out for two different operating temperatures viz. 35 °C and 45 °C. The results of the investigation indicate that the austempered castings show higher UTS values (34% increase), elongation values (24.2% increase) and hardness values (12.05% increases) as compared to the as-cast condition. From the corrosion studies, it is seen that austempered specimens exhibit lower weight loss (34% improvement), lower corrosion rate (33% improvement) compared to the as-cast specimens.

- **R G Baligidad and Shivkumar Khaple** [2008] have investigated the effect of cerium content and thermo mechanical processing on structure and properties of Fe–10·5 wt.% Al–0·8 wt. % C alloy has been investigated. The ESR ingots were hot-forged and hotrolled at 1373 K as well as warm-rolled at 923 K and heat-treated. The ternary, Fe–10·5 wt.%Al–0·8 wt.%C alloy showed the presence of two phases; Fe–Al with bcc structure, and large volume fraction of Fe3AlC0·5 precipitates. Addition of cerium to Fe–10·5 wt.%Al–0·8 wt.%C alloy resulted in three phases, the additional phase being small volume fraction of fine cerium oxy-carbide precipitates. Improvement in tensile elongation from 3–6·4% was achieved by increasing the cerium content from 0·01–0·2 wt.% and further improvement in tensile elongation from 6·4–10% was achieved by warm-rolling and heat treatment.

- **H. R. Erfanian-Naziftoosi,** have investigate on The Effect of Isothermal Heat Treatment Time on the Microstructure and Properties of 2.11% Al ADI. the bainitic transformation during austempering was studied for a 2.11% Al containing ductile iron under different isothermal holding times. The austenitizing time and temperature were selected to be 60 min and 920 ° C, respectively, referring to previous studies. The isothermal austempering heat treatments were performed at 350°C for different duration. Micro structural investigations revealed that austempering treatment at 350°C for durations up to 100 min results in microstructures consisting of carbide-free bainitic ferrite with considerable amounts of retained austenite while the extension of isothermal transformation time leads to precipitation of carbides. Hardness measurements were also carried out the results of which were shown to be consistent with micro structural evolutions.

- **M. Cemal Cakir** [2007] has Investigating the machinability of ADI having different austempering temperatures and times. ADI bars that were austempered at various temperatures and times and the machinability is investigated by adopting tool life, tool wear rate, cutting forces, and surface finish produced on a job as general criteria. Machinability tests were carried out according to ISO 3685: 1993 (E) standard “Tool Life Testing with Single Point Turning Tools” on eight different ADI structures, austempered at 250, 300, 350 and 400 °C for 1 and 2 h. Cutting forces, flank wear and surface roughness values were measured throughout the tool life and the machining performance of ADI having different structures were compared. In the machinability tests structures austempered at 300 C for 1 h and 2 h were observed to produce unexpected results. That is to say, structures having less hardness values seemed to wear the tool faster than the harder structures. In order to investigate the grounds of this case, some more tests on these structures were conducted.

- **M.Tadayon saidi et al.** [2007] have investigate effect of heat treatment cycle on the mechanical properties of machinable austempered ductile iron. Y-blocks, spheroid formation and inoculation FeSi were used. Chemical composition of sample 3.24 % C, 3.7 % Si, 0.35 % Mn, 0.97 % Ni, 0.6 % Cu, 0.25 % Mo. Different cycle of austempering process (austenitization and austempering cycle) applied i.e. Austenite at 750°C , 800° C ,850°C ,and 900°C for 1, 2 and 3 hour Austempered at 350°C, 390°C and 395° C for 1, 2 and 3 hour, conclusion could be summarized, optimum machinability due to suitable tensile properties can achieve by austeniting at 850°C & austempering at 395°C. The yield strength & tensile strength increase with increasing austenitizing temperature. With increasing austenite temperature the elongation is increased up to 850°C & minimum elongation was achieved by austenizing at 850°C & austempered at 390°C.

- **G.S.Cho et al.**[2007] The effects of alloying elements on the as-cast microstructures and mechanical properties of heavy section ductile cast iron were investigated to develop press die material having high strength and high ductility. Measurements of ultimate tensile strength, 0.2% proof strength, elongation and unnotched Charpy impact energy are presented as a function of alloy amounts within 0.25 to 0.75 wt pct range. Hardness is measured on the broken tensile specimens. The small additions of Mo, Cu, Ni and Cr changed the as-cast mechanical properties owing to the different as-cast matrix microstructures. The ferrite matrix of Mo and Ni alloyed cast iron exhibits low strength and hardness as well as high elongation and impact energy. The increase in Mo and Ni contents developed some fractions of pearlite structures near the austenite eutectic cell boundaries, which caused the elongation and impact energy to drop in a small range. Adding Cu and Cr elements rapidly changed the ferrite matrix into pearlite matrix, so strength and hardness were significantly increased. As more Mo and Cr were added, the size and fraction of primary carbides in the eutectic cell boundaries increased through the segregation of these elements into the intercellular boundaries.

- **P.W. Shelton, A.A. Bonner**, describes the effect on the mechanical properties of elemental copper additions (above the levels of solid solubility), to a commercial ADI composition and micro structural studies are used to determine the distribution of the copper. Two types of compositions were prepared with different compositions. The composition of first and second sample were C 3.5%, Si 2.5%, Cu 1.5%, Mo 0.4% and C 3.5%, Si 2.5%, Cu 0.8%, Mo 0.73% and rest were other elements.

- **Olivir. Ericet**, Investigates the austermping study of alloyed ductile iron. The ductile iron alloyed with 0.45% Cu and austempered at different time and temperatures range. After this the effect of this heat treatment on the microstructure and mechanical properties of ADI was analyzed.

- **Gulcan Toktas et al.**[2007],studied Influence of matrix structure on the fatigue properties of an alloyed ductile iron. Rotary bending fatigue tests were conducted on ductile iron containing 1.25 wt% nickel, 1.03 wt% copper and 0.18 wt% molybdenum with various matrix structures. Several heat treatments were applied to obtain ferritic, pearlitic/ferritic, pearlitic, tempered martensitic, lower and upper ausferritic structures in the matrix of a pearlitic as-cast alloyed ductile iron. The tensile properties (ultimate tensile strength, 0.2% yield strength and percent elongation), the hardness and the microstructures of the matrixes were also investigated in addition to fatigue properties. Fractured surfaces of the fatigue specimens were examined by the scanning electron microscope. The results showed that the lowest hardness, tensile and fatigue properties were obtained for the ferritic structure and the values of these properties seemed to increase with rising pearlite content in the matrix. While the lower ausferritic structure had the highest fatigue strength, the upper ausferritic one showed low fatigue and tensile properties due to the formation of the second reaction during the austempering process.

- **A.N. Damir, A. Elkhatib, G. Nassef** [2006] have investigate on Prediction of fatigue life using modal analysis for grey and ductile cast iron. investigate the capability of experimental modal analysis, as a nondestructive tool, to characterize and quantify fatigue behavior of materials. This is achieved by studying the response of modal parameters (damping ratio, natural frequency, and FRF magnitude) to variations in material microstructure, as a main factor affecting fatigue life. This helps in correlating modal parameters to fatigue behavior. Cast iron family represented by grey cast iron, ductile cast iron and austempered ductile iron (ADI) is used in experiments as a case presenting considerable variations in microstructure. Modal testing was performed on specimens made of the selected materials in order to extract the corresponding modal parameters. Rotating bending fatigue test was performed on standard fatigue specimens to correlate the modal parameters to the fatigue behavior. This enables the evaluation of the ability of modal testing to predict the fatigue life of mechanical components.

- **O. Eric, L. Sidjani**, studied the effect of austempering on the microstructure and toughness of nodular cast iron alloyed with molybdenum, copper, nickel, and manganese. The Chemical composition of CuNiMo SG ductile iron were divided in three groups as Light microscopy , scanning electron microscopy , and X-ray diffraction technique were performed for micro structural characterization, whereas impact energy test was applied for toughness measurement. Specimens were austenitized at 860 °C, then austempered for various times at 320 and 400 °C, followed by ice-water quenching.

Objective of work

- From the literature review it is seen that austempered ductile iron as an engineering material has found increasing applications over the years since its discovery because of its excellent mechanical properties such as high strength, toughness, good wear resistance, good machinability and all that at low cost. The excellent mechanical properties of ADI material are due to its unique microstructure of ausferrite which consists of high carbon austenite and bainitic ferrite with graphite nodules dispersed in it. The austempered microstructure is a function of the austempering time and temperature and therefore achieving excellent mechanical properties depends on selection and control of proper austempering time and temperature.

- Therefore, an attempt has been made in the present work to study the effect of austempering temperature and time on the mechanical properties of austempered ductile iron such as tensile strength, % elongation, hardness and impact toughness by carrying out austempering treatment of ductile iron at 350°C, 300°C, and 250°C for 0.5hr, 1hr, 1.5hrs and 2hrs.

Experimental Procedure

- The experimental procedure for the project work can be listed as :
  - Sample casting.
  - Specimen preparation.
  - Heat treatment process.
  - Mechanical testing.
  - Micro structural observation.

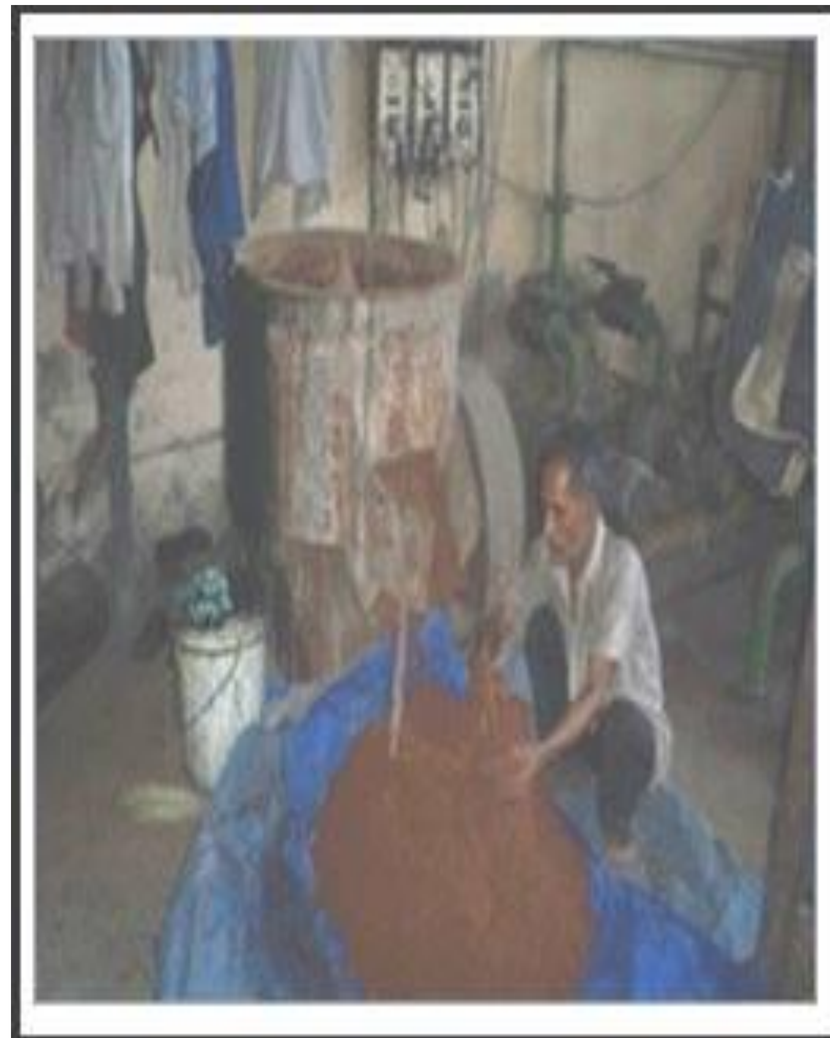
Sand Casting

- Experiments were carried out in induction furnace with 500 kg Capacity Crucible furnace.
- Metallic charge were composed of pig iron, commercially ferro silicon, steel scrap .
- Nominal composition of the experimental alloy is given below.

Material	C	Si	Mn	P	S	Mg
SGI	3.680	2.030	.0380	0.030	0.014	0.038

Sand Preparation

- The sand preparation as shown in figure. Sand was prepared by addition of special additives to improve mould ability of sand and casting finish.

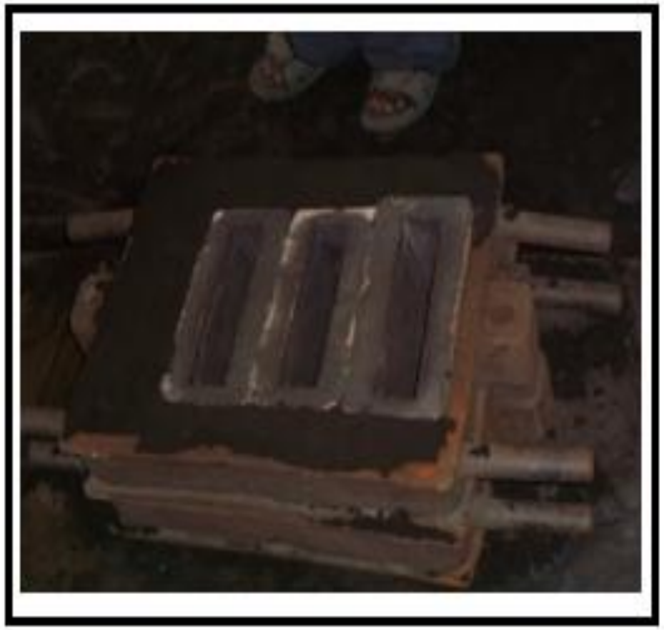


Pattern making

- The pattern resembles the real casting part to generate cavity inside the mold. In present experiment Y-block was used as shown in figure

Moulding

- As shown in figure and 3.4, molding requires the ramming of sand around the pattern. As sand is packed, it develops strength and becomes rigid within the flask.



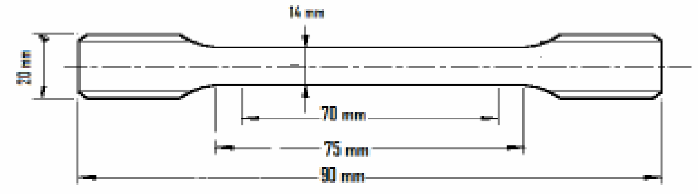
Pouring

- As shown in figure 3.5 pouring of molten metal to the mould carried out. The additive is added during pouring for slag removing and temperature control.

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 GAY NODULE INDUCTO CAST PVT.LTD. The sample that we got was GGG-40 S.G Cast 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



Heat Treatment Process

- Nine samples were taken in a group. To homogenize the samples kept them in a muffle furnace for one hour at 850^{o}C, some samples were conventionally treated and some were austempered for different times with constant temperature.
- **Austempering process**

  For austempering process as shown in figure, the samples were heated at 850°C for 1hr. for austenisation and then transferred quickly to a salt bath (salt combination was 50 wt. % NaNO3 and 50 wt. % NaNO2) maintained at 250 °C.

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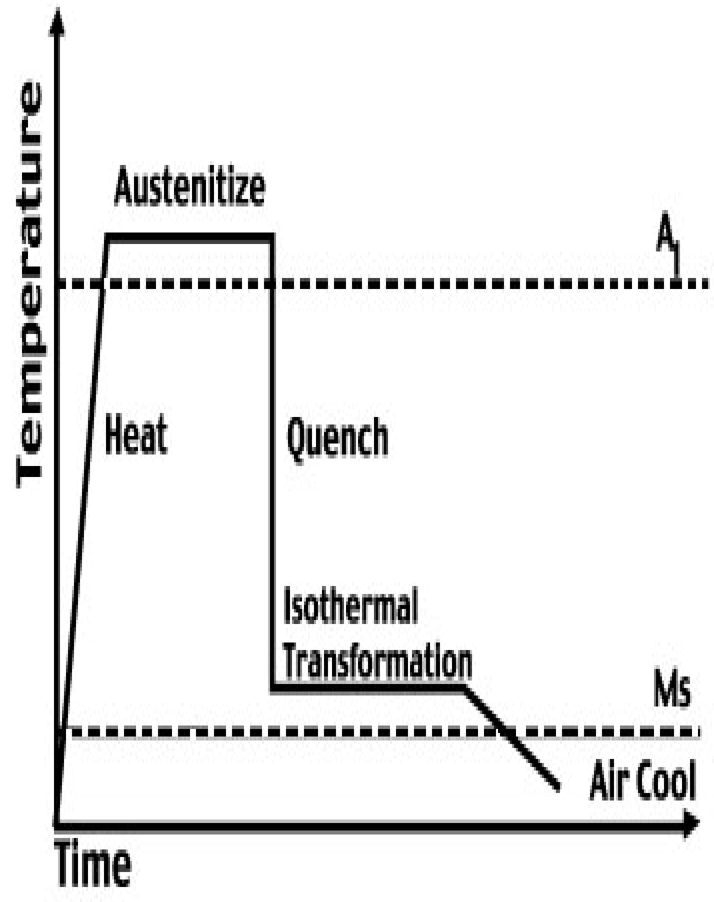
- The samples were kept in the salt bath for different times as 30 minutes, 1hr. and 1.5 hrs. After which they were allowed to cool in still air. The isothermal austempering cycle used in this study is shown in figure.



Different austempering condition

Austenizing Temperature in °C	SALT BATH TEMP. IN °C	TIME IN hr.	Observation
850 °C	250 °C	½	
		1	
		1 ½	
	300 °C	½	
		1	
		1 ½	
	350 °C	½	
		1	
		1 ½	

Hardness Measurement

The heat treated samples of dimension 8×8×3 mm were polished in emery papers(or SiC papers) of different grades for hardness measurement. Rockwell Hardness test was performed at room temperature to measure the macro hardness of the ductile iron specimens in A scale. The load was applied through the square shaped diamond indenter for few seconds during testing of all the treated and untreated samples. Four measurements for each sample were taken covering the whole surface of the specimen and averaged to get final hardness results. A load of 60 kg was applied to the specimen for 30 seconds. Then the depth of indentation was automatically recorded on a dial gauge in terms of arbitrary hardness numbers. Then these values were converted to in terms of required hardness numbers (as Brielle's or Vickers hardness numbers).

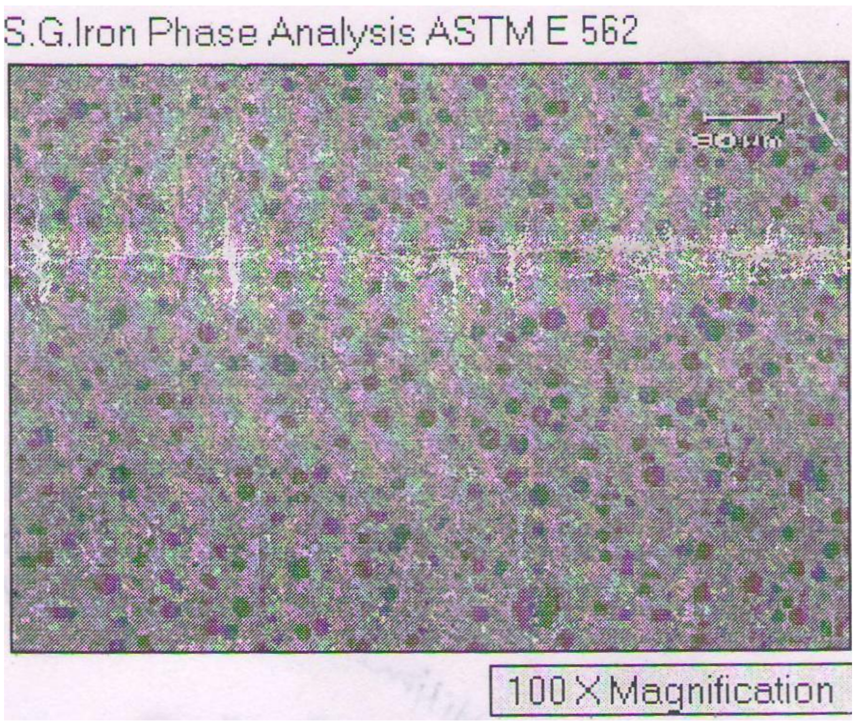
Tensile Testing

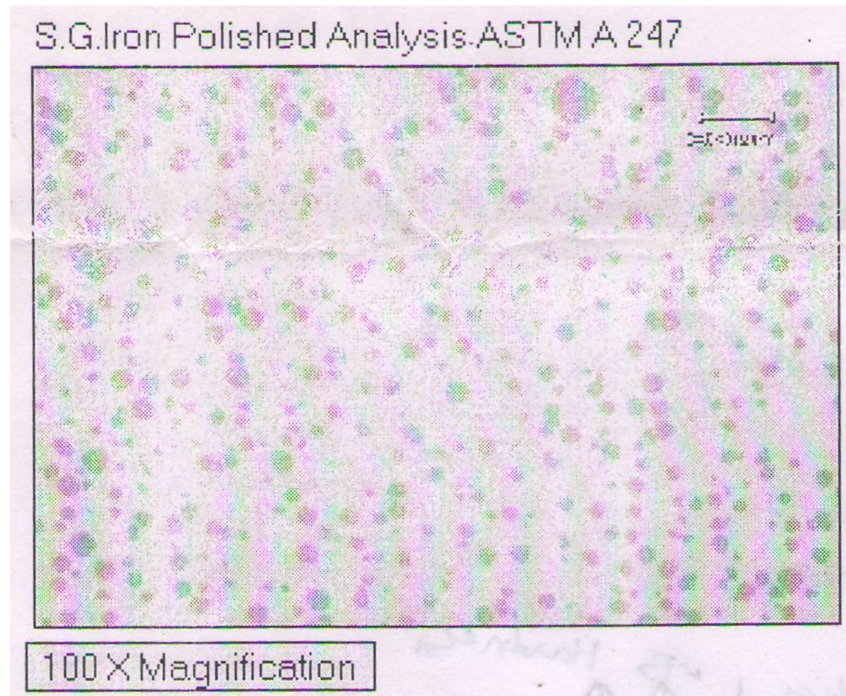
- Tensile test were carried out according to ASTM (A 370-2002). Specimens of "Dog Bone Shape" shown in figure 3.2 were prepared for tensile test, which were machined to 5mm gauge diameter and 30 mm gauge length. Test were conducted by using Instron 1195 universal testing machine connected to computer to draw the stress–strain curves and recording the tensile strength, 0.2 proof stress and elongation. Test were performed at room temperature (298K) with strain rate of 9×10^{-3} up to fracture. The tensile load of 50 KN was applied to the specimen up to the breaking point.
- Advanced materials are used in a wide variety of enviournments and at different temperature and pressure. It is necessary to know the elastic and plastic behavior of these materials under such conditions. Such properties as tensile strength, creep strength, fatigue strength, fracture strength, fracture toughness, and hardness characterize that behavior. These properties can be measured by mechanical tests.

Micro-structural observations:

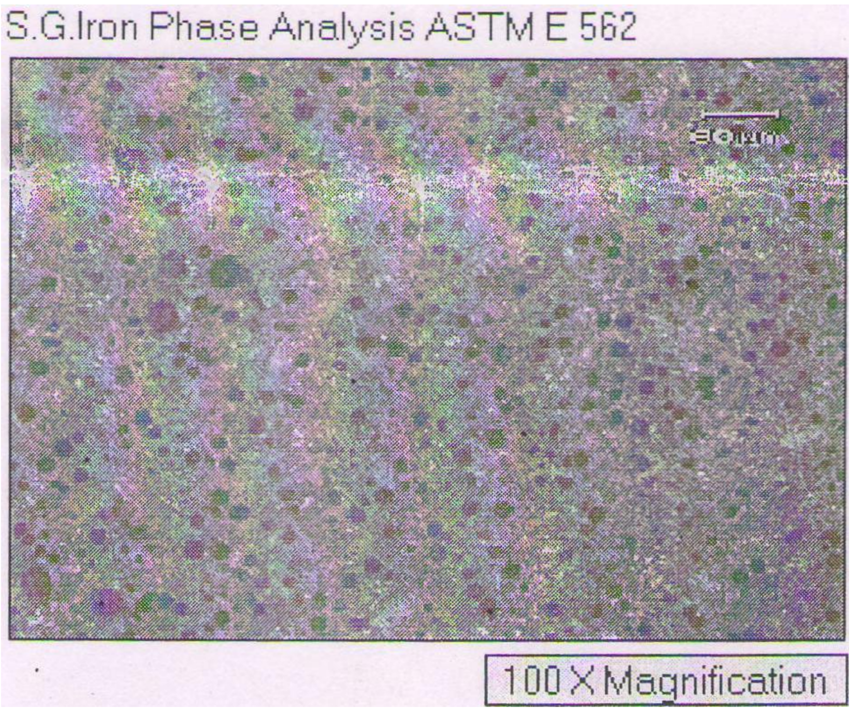
Before and after heat treatment, the samples were prepared for micro structural analysis. From each specimen a slice of 4 mm is cut to determine the microstructure. These slices are firstly mounted by using Bakelite powder then polished in SiC paper of different grades (or emery papers) then in 1 μ m cloth coated with diamond paste. The samples were etched using 2% nital (2% conc. Nitric acid in methanol solution). Then the microstructures were taken for different heat treated specimen by using Image Analyzer microscope.

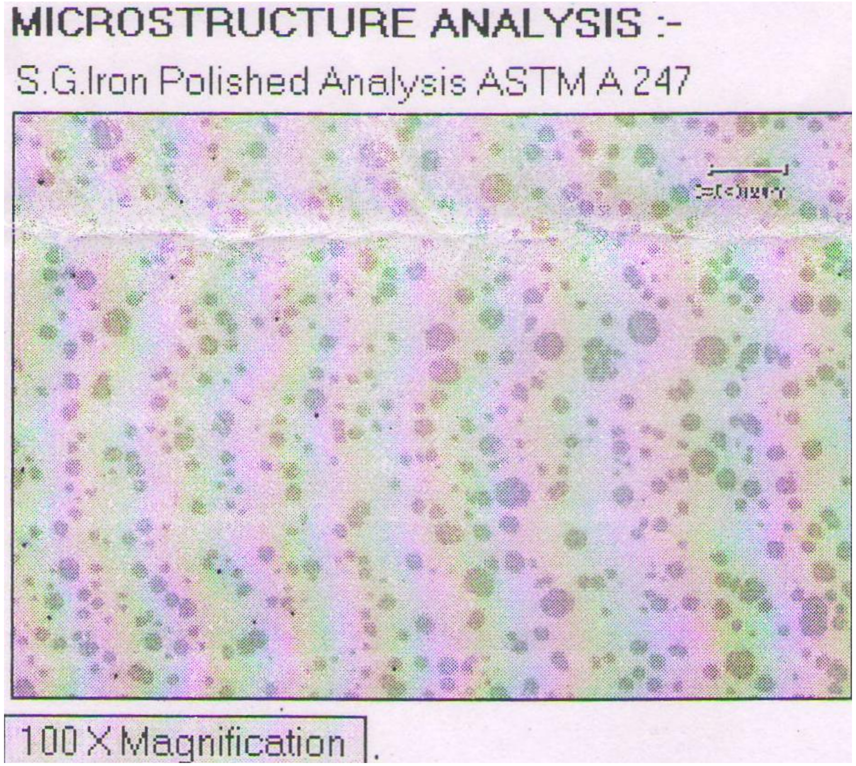
Microstructure of casting at Austempered at 250 °C for 30 min.



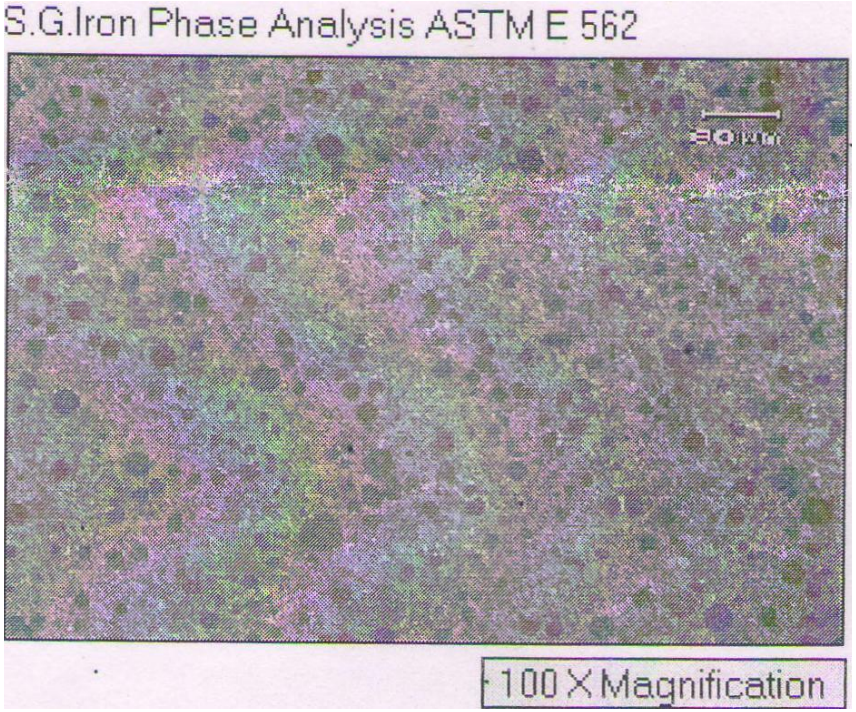


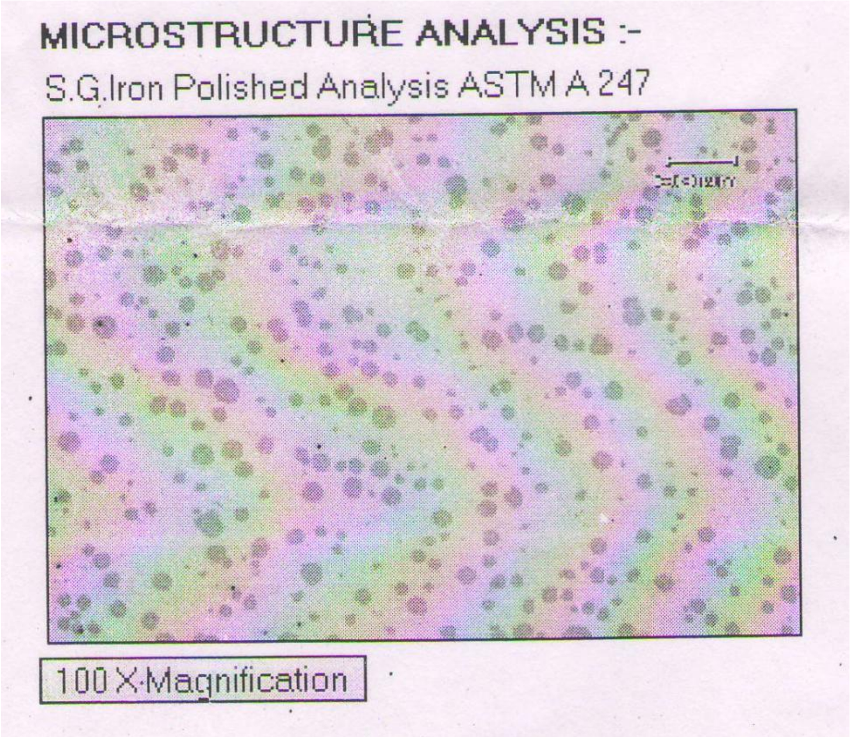
Microstructure of casting at Austempered at 250 °C for 60 min.



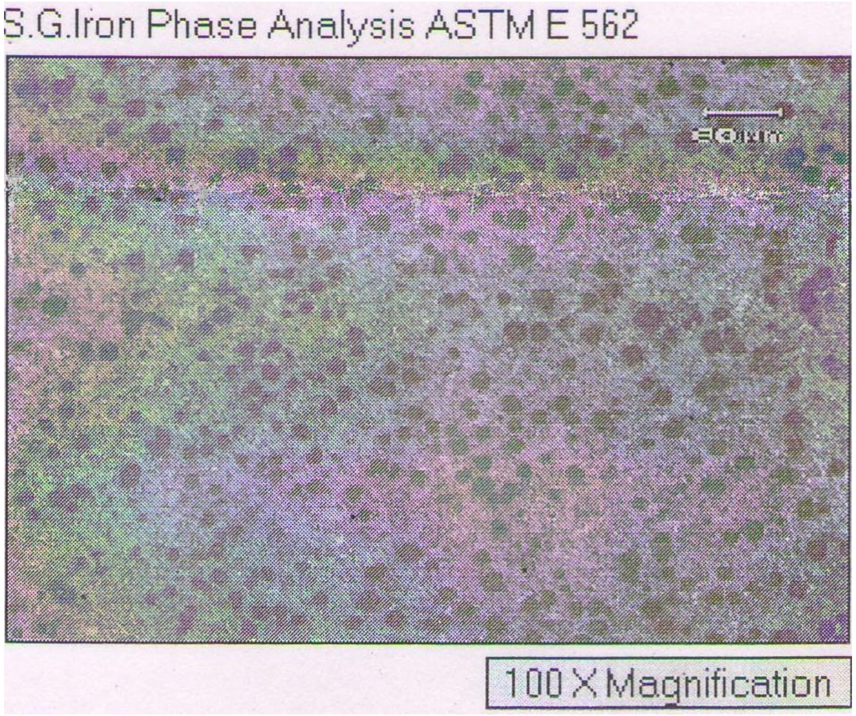


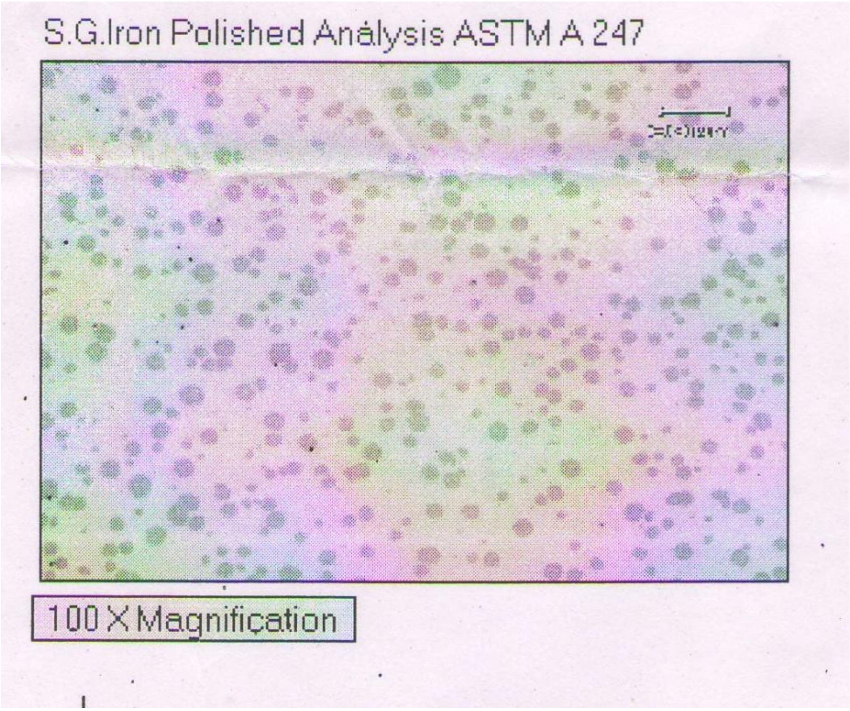
Microstructure of casting at Austempered at 250 °C for 90 min.



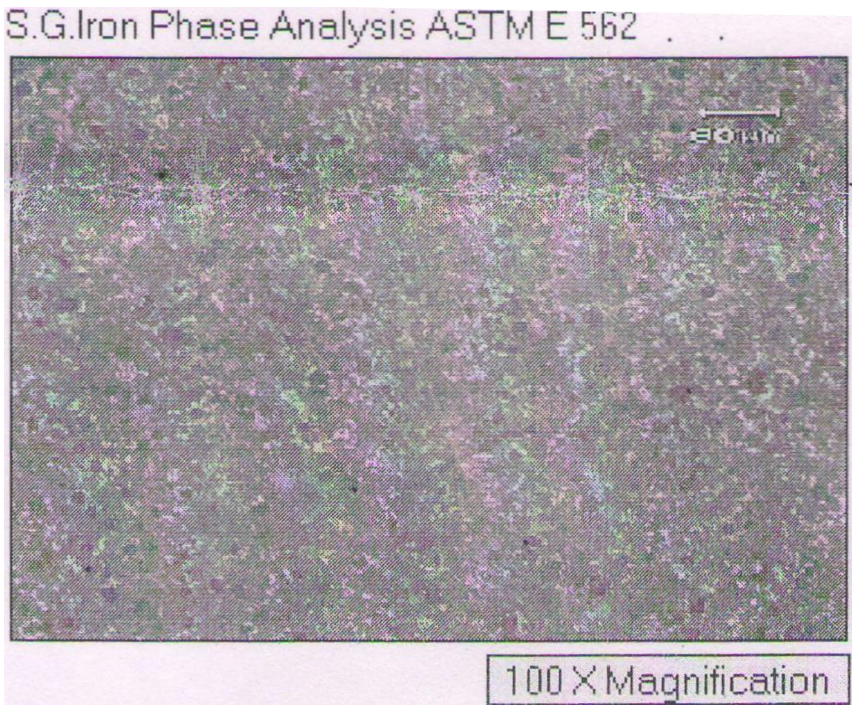


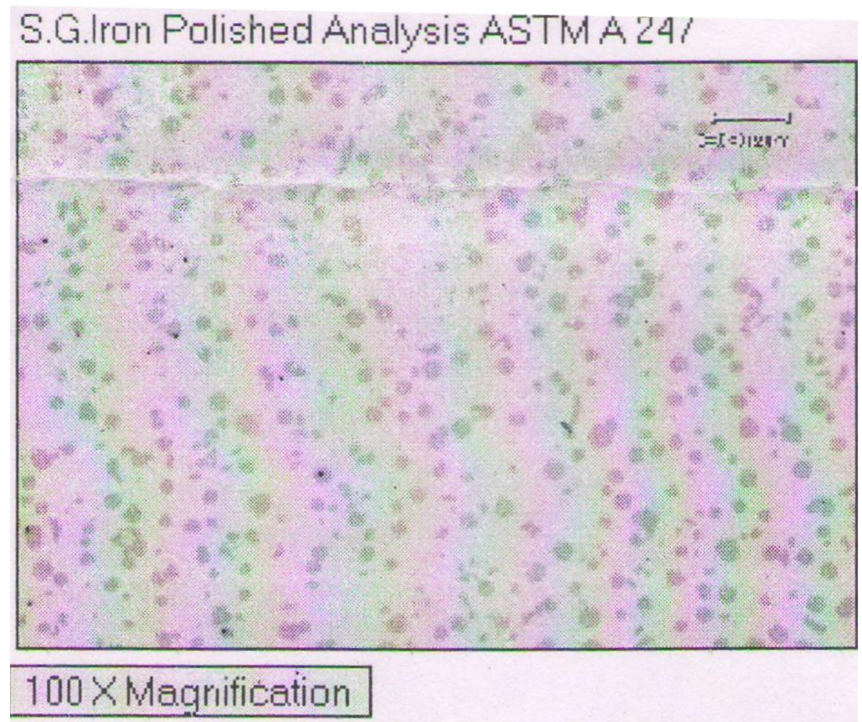
Microstructure of casting at Austempered at 300 °C for 30 min.



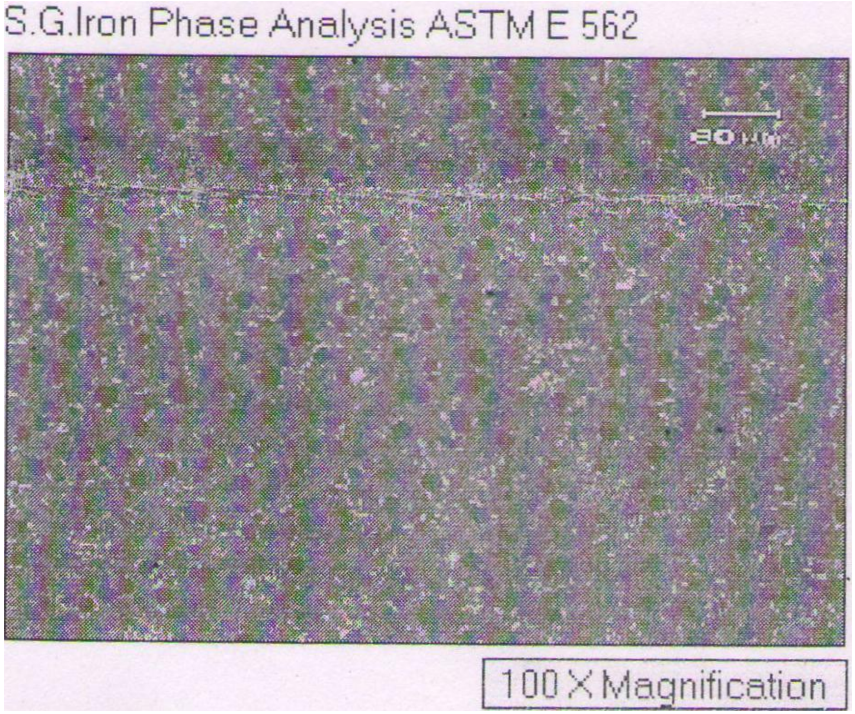


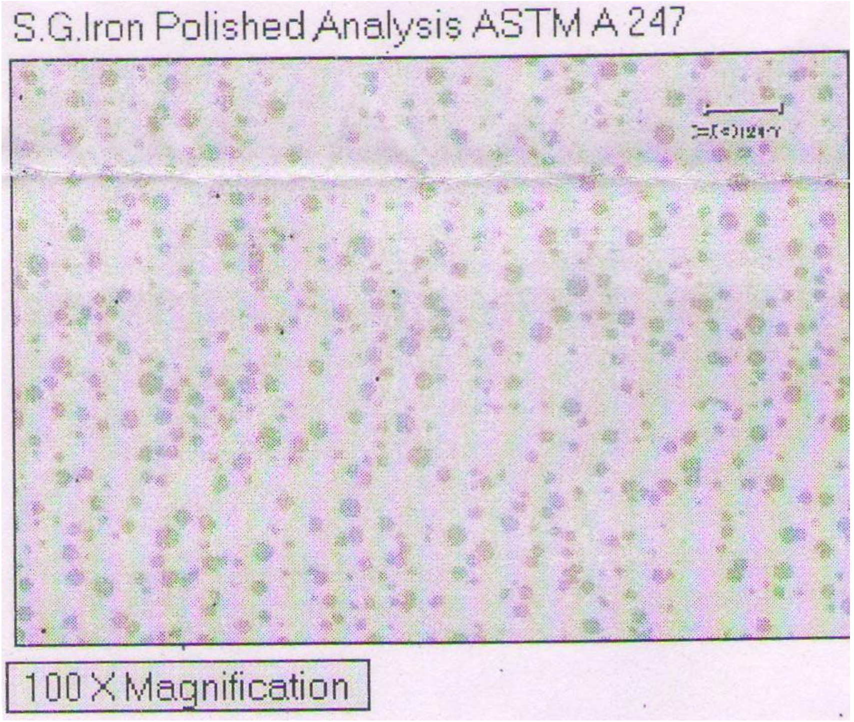
Microstructure of casting at Austempered at 300 °C for 60 min.



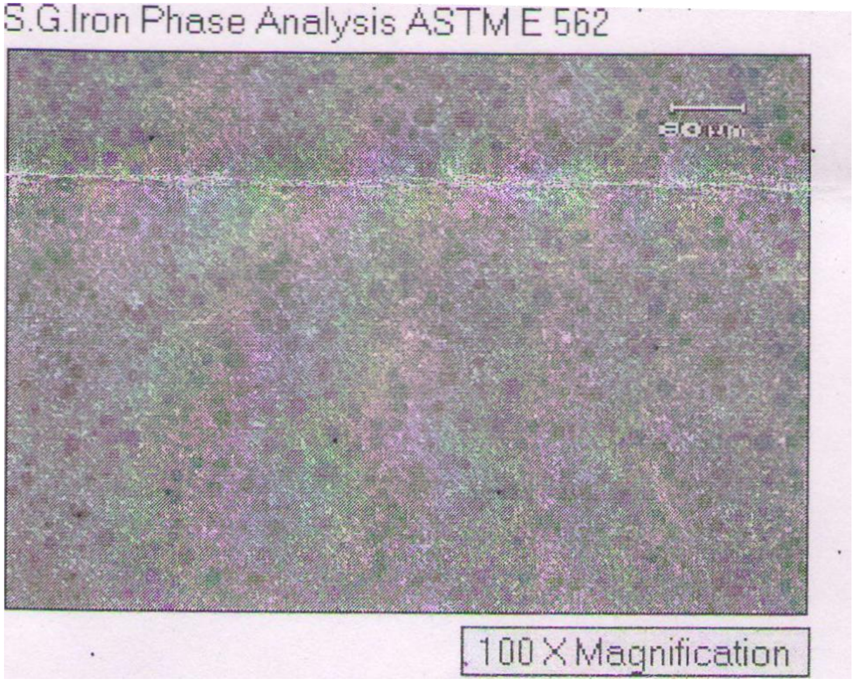


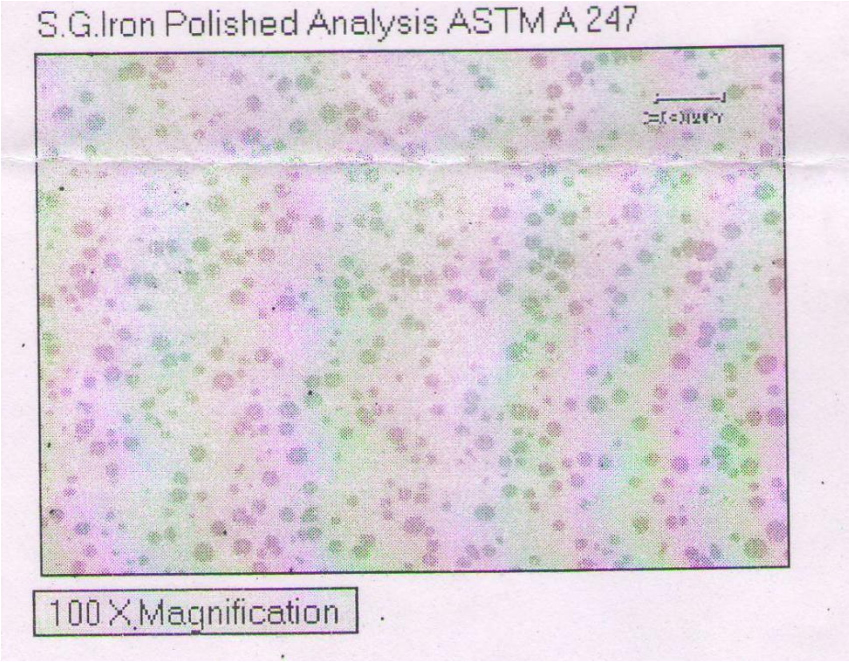
Microstructure of casting at Austempered at 300 °C for 90 min.



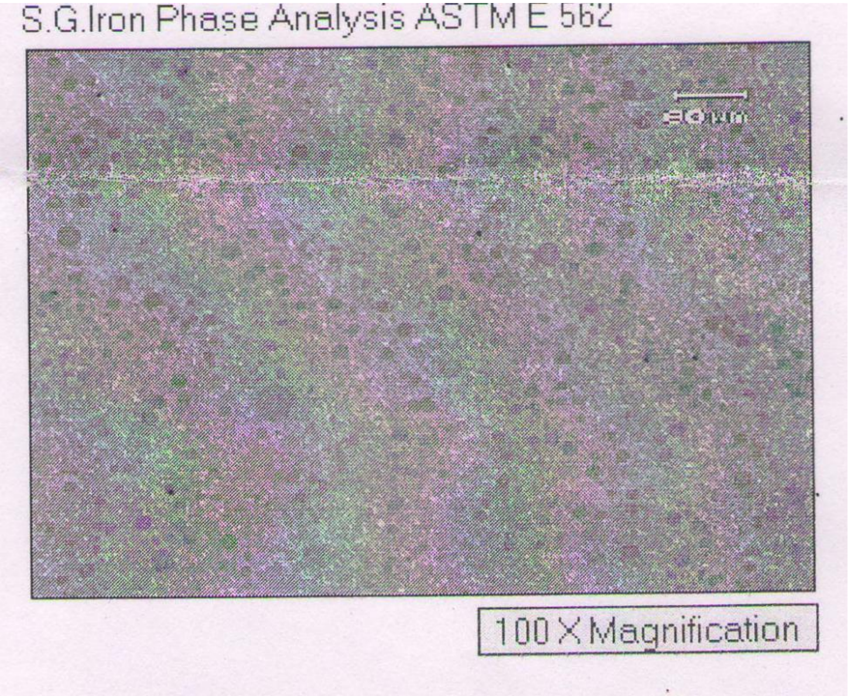


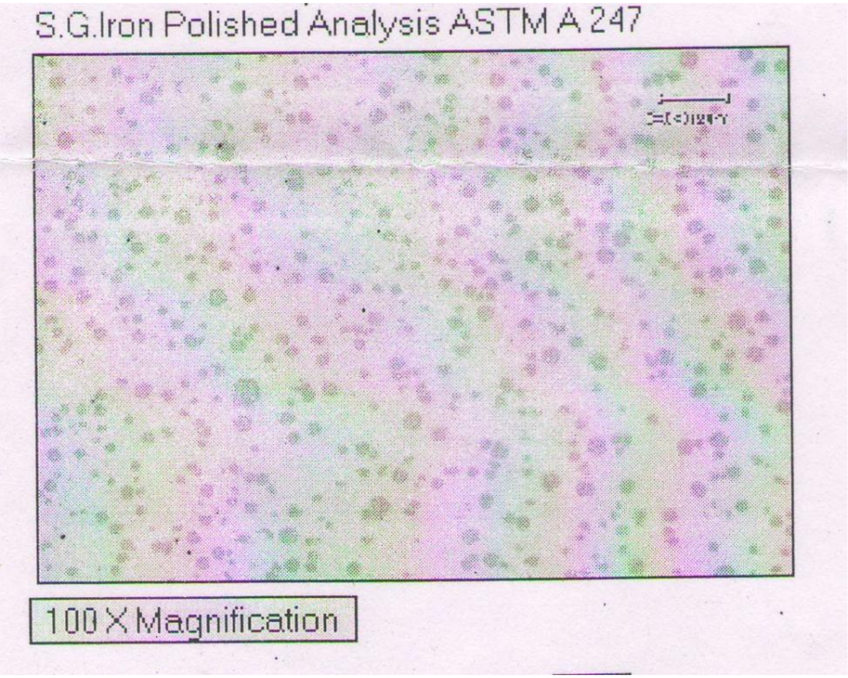
Microstructure of casting at Austempered at 350 °C for 30 min.



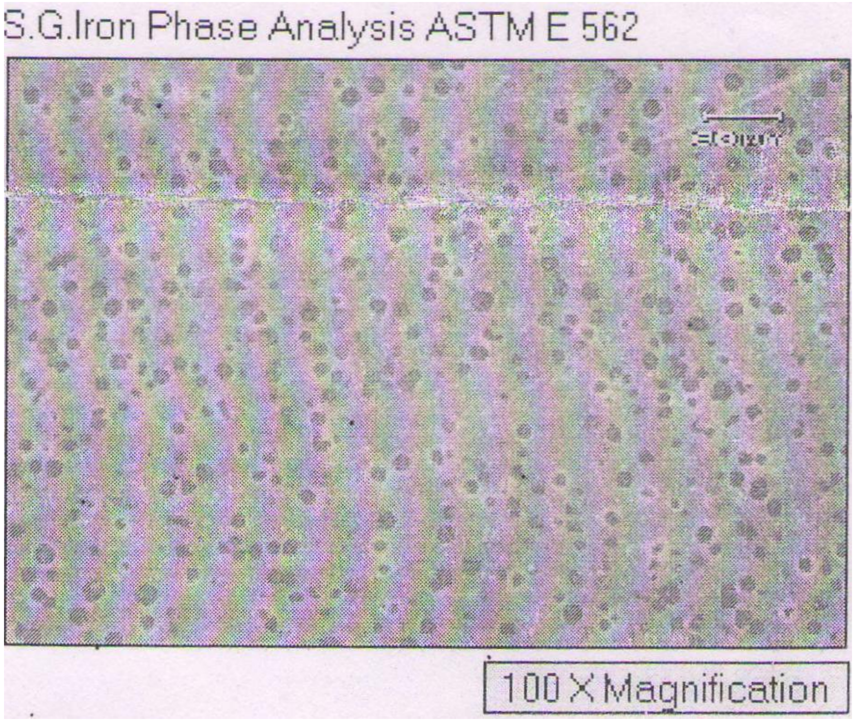


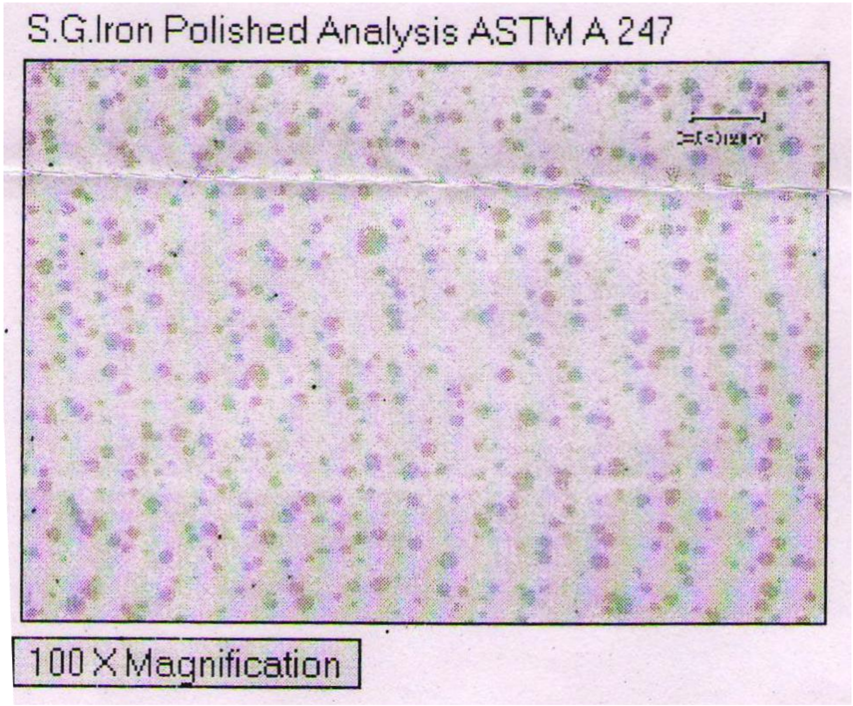
Microstructure of casting at Austempered at 350 °C for 60 min.



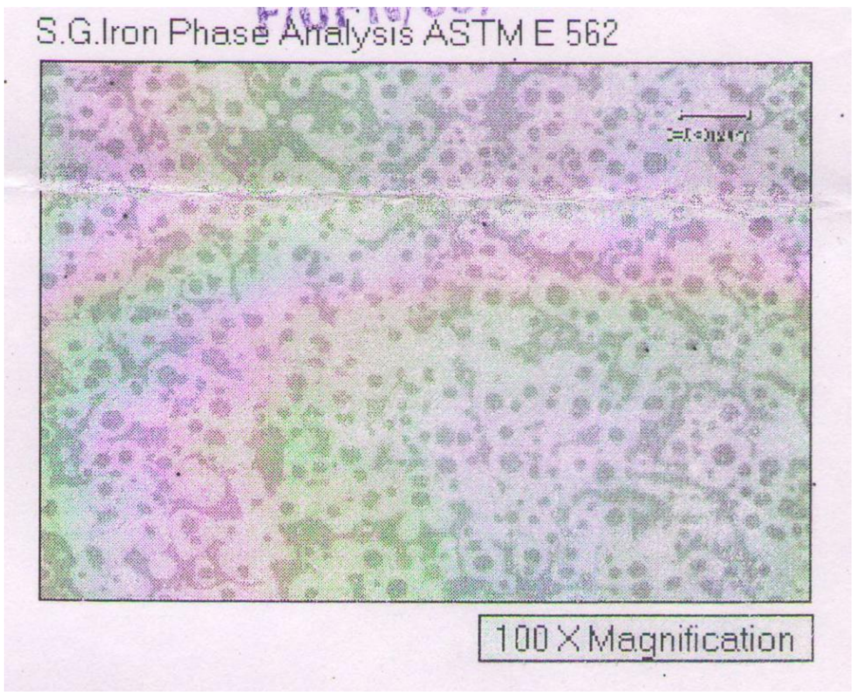


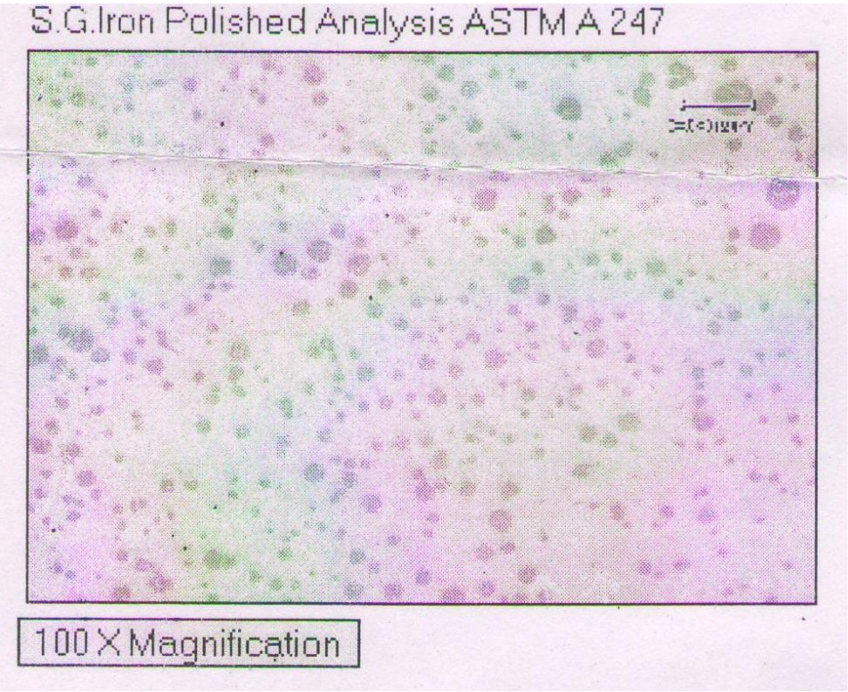
Microstructure of casting at Austempered at 350 °C for 90 min.





Microstructure of casting as cast condition



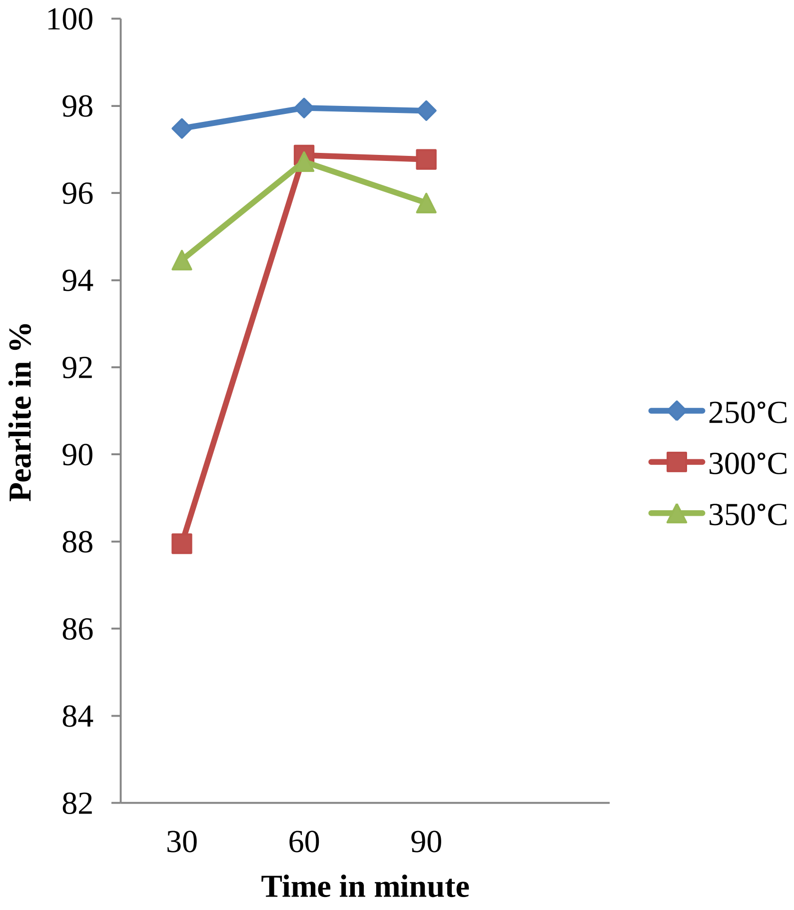


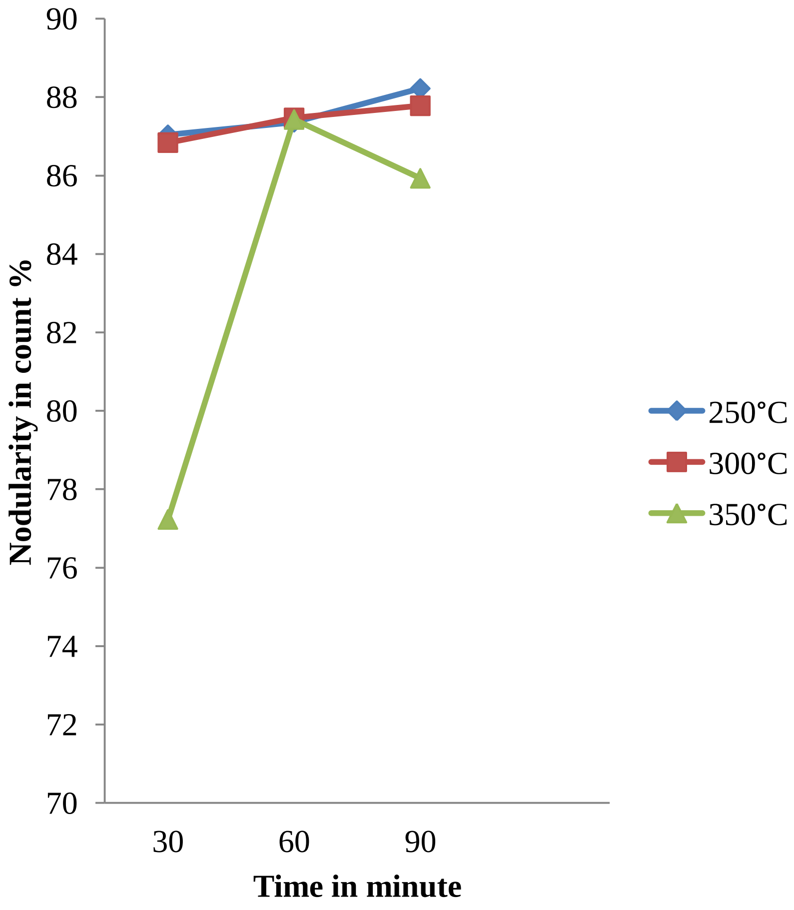
Micro structural Result

- In present investigation micro structural parameter pearlite, ferrite, average nodularity are shown in table.

Condition	Pearlite (%)	Ferrite (%)	Average nodularity (%)
Austempered at 250 °C for 30 min.	97.48	2.52	87.04
Austempered at 250 °C for 60 min.	97.95	2.05	87.36
Austempered at 250 °C for 90 min.	97.89	2.11	88.22
Austempered at 300 °C for 30 min.	8.95	12.05	86.84
Austempered at 300 °C for 60 min.	96.87	3.12	87.47
Austempered at 300 °C for 90 min.	96.77	3.23	87.78
Austempered at 350 °C for 30 min.	94.46	5.54	77.23
Austempered at 350 °C for 60 min.	96.72	3.28	87.43
Austempered at 350 °C for 90 min.	95.77	4.23	85.93
Without heat treatment as Cast.	22.35	77.65	86.07

The value of pearlite is increase at 250 °C with different time duration as compare to temperature 300 °C and 350 °C with different time duration. As shown in fig. 4.4 pearlite is maximum at 250 °C and 60 minute. The value nodularity percentage at 250 °C, 300 °C, 350 °C with different time duration as shown in figure 4.5.





Mechanical property of casting

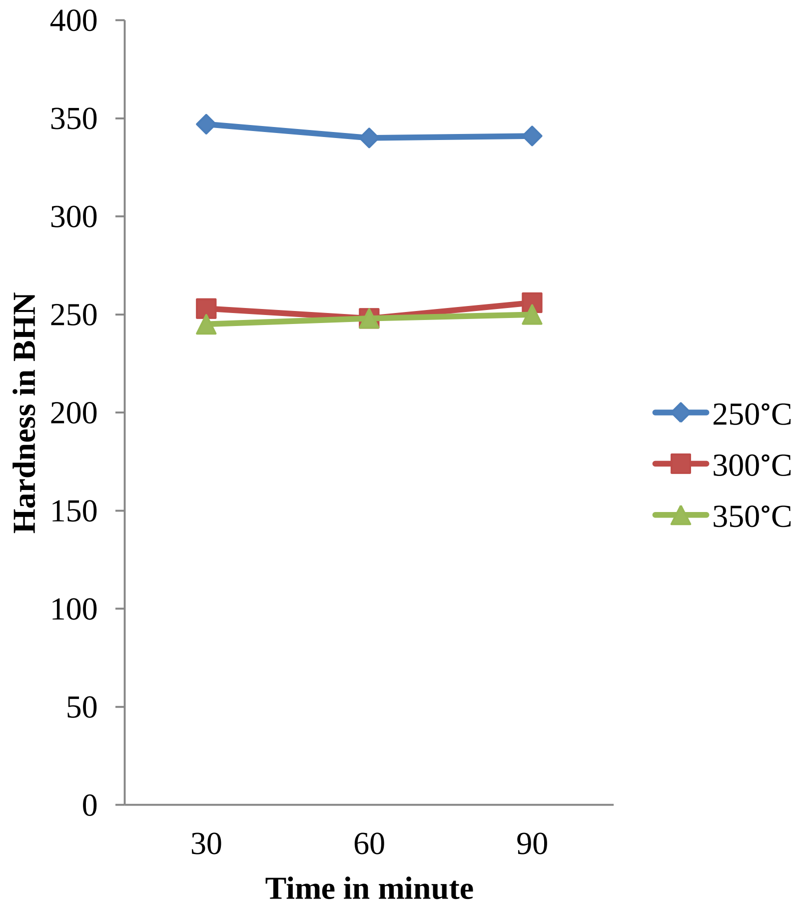
In present investigation measured hardness, ultimate tensile strength (UTS) for sand casting. Table shows value of mechanical property of casting.

Condition	UTS(N/mm^2)	Hardness(BHN)	Elongation (%)
Austempered at 250 °C for 30 min.	1131.49	347	2.94
Austempered at 250 °C for 60 min.	1169.38	340	2.8
Austempered at 250 °C for 90 min.	1137.97	341	3.06
Austempered at 300 °C for 30 min.	804.16	253	4.39
Austempered at 300 °C for 60 min.	882.19	248	5
Austempered at 300 °C for 90 min.	851.14	256	5.91
Austempered at 350 °C for 30 min.	824.78	245	4.66
Austempered at 350 °C for 60 min.	836.12	248	4.82
Austempered at 350 °C for 90 min.	833.88	250	4.48
Without heat treatment as Cast.	495.20	166	13.81

Hardness

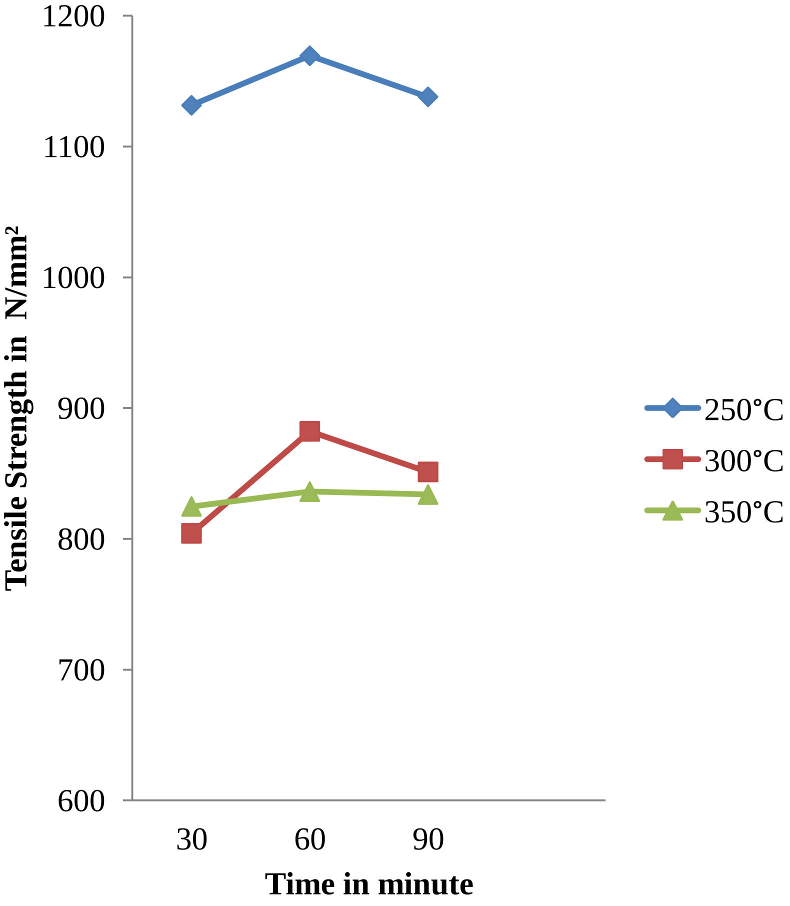
In present investigation Hardness, Ultimate Tensile Strength (UTS) were measured also Micro-structure were investigated.

- The value of hardness is increase at 250 °C with different time duration as compare to temperature 300 °C and 350 °C with different time duration. As shown in fig. 4.1 obtain the hardness of casting at a given temperature is decrease with increase in time and further increase in time gives increasing in hardness value but less than first condition. The value of pearlite is maximum at 250 °C and 30 minute due to this maximum hardness is 347 BHN obtained as compare to at 300 °C and 350 °C.



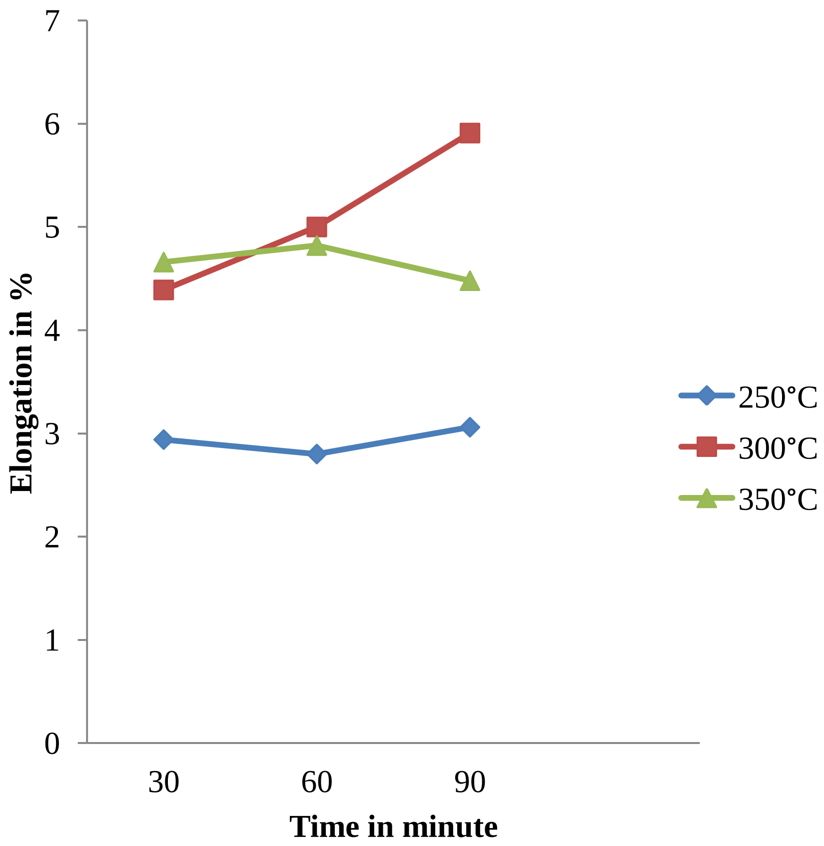
Tensile strength

- The value of UTS is increase at 250 °C with different time duration as compare to temperature 300 °C and 350 °C with different time duration. As shown in fig. 4.2 obtain Ultimate Tensile Strength of casting at a given temperature is increase with increase in time and further increase in time gives decreasing in Ultimate Tensile Strength value but more than first condition. The value of pearlite is maximum at 250 °C and 60 minute due to this maximum Ultimate Tensile Strength is 1169.38 N/mm² obtained as compare to at 300 °C and 350 °C.



Elongation

- The value of elongation is increase at 300 °C with different time duration as compare to temperature 250 °C and 350 °C with different time duration. As shown in fig. 4.3 obtain elongation of casting at a given temperature is increase with increase in time and further increase in time gives increasing in elongation % . The value of pearlite is maximum at 250 °C and 60 minute due to this minimum elongation is 2.8 % obtained as compare to at 300 °C and 350 °C.



Discussion

Case I: The samples were heated at 850°C for 1h for austenisation and then transferred quickly to a salt bath maintained at 250°C for different time duration.

- With reference to Table 3.4, in case of 30 minute tempering obtain value of hardness 347 BHN, Ultimate tensile strength 1131.49 (N/mm^2) and elongation 2.94 %. With reference to Table 3.3 phase analysis shows pearlite 97.48 %, microstructure shows average nodularity of casting obtained 87.04 %.
- With reference to Table 3.4, in case of 60 minute tempering obtain value of hardness 340 BHN, Ultimate tensile strength 1169.38 (N/mm^2) and elongation 2.8 %. With reference to Table 3.3 phase analysis shows pearlite 97.95 %, microstructure shows average nodularity of casting obtained 87.36 %.
- With reference to Table 3.4, in case of 90 minute tempering obtain value of hardness 341 BHN, Ultimate tensile strength 1137.97 (N/mm^2) and elongation 3.06 %. With reference to Table 3.3 phase analysis shows pearlite 97.89 %, microstructure shows average nodularity of casting obtained 88.22 %.
- The value of pearlite is maximum at 250 °C and 60 minute due to this maximum Ultimate Tensile Strength is 1169.38 N/mm^2 obtained as compare to at 30 minute and 90 minute. The value of hardness is maximum at 250 °C and 30 minute is 347 BHN obtained as compare to at 60 minute and 90 minute.

Continue…

Case II: The samples were heated at 850°C for 1h for austenisation and then transferred quickly to a salt bath maintained at 300°C for different time duration.

- With reference to Table 3.4, in case of 30 minute tempering obtain value of hardness 253 BHN, Ultimate tensile strength 804.16 (N/mm^2) and elongation 4.39 % . With reference to Table 3.3 phase analysis shows pearlite 87.95 %, microstructure shows average nodularity of casting obtained 86.84 %.
- With reference to Table 3.4, in case of 60 minute tempering obtain value of hardness 248 BHN, Ultimate tensile strength 882.19 (N/mm^2) and elongation 5 % . With reference to Table 3.3 phase analysis shows pearlite 96.87 %, microstructure shows average nodularity of casting obtained 87.47 %.
- With reference to Table 3.4, in case of 90 minute tempering obtain value of hardness 256 BHN, Ultimate tensile strength 851.14 (N/mm^2) and elongation 5.91 % . With reference to Table 3.3 phase analysis shows pearlite 96.77 %, microstructure shows average nodularity of casting obtained 87.78 %.
- The value of pearlite is maximum at 300 °C and 60 minute due to this maximum Ultimate Tensile Strength is 882.19 N/mm^2 obtained as compare to at 30 minute and 90 minute. The value of hardness is maximum at 300 °C and 90 minute is 256 BHN obtained as compare to at 30 minute and 60 minute.

Continue…

Case III: The samples were heated at 850°C for 1h for austenisation and then transferred quickly to a salt bath maintained at 350°C for different time duration.

- With reference to Table 3.4, in case of 30 minute tempering obtain value of hardness 245 BHN, Ultimate tensile strength 824.78 (N/mm^2) and elongation 4.66 % . With reference to Table 3.3 phase analysis shows pearlite 94.46 %, microstructure shows average nodularity of casting obtained 77.23 %.
- With reference to Table 3.4, in case of 60 minute tempering obtain value of hardness 248 BHN, Ultimate tensile strength 836.12 (N/mm^2) and elongation 4.82 % . With reference to Table 3.3 phase analysis shows pearlite 96.72 %, microstructure shows average nodularity of casting obtained 87.43%.
- With reference to Table 3.4, in case of 90 minute tempering obtain value of hardness 250 BHN, Ultimate tensile strength 833.88 (N/mm^2) and elongation 4.48 % . With reference to Table 3.3 phase analysis shows pearlite 95.77 %, microstructure shows average nodularity of casting obtained 85.93 %.
- The value of pearlite is maximum at 350 °C and 60 minute due to this maximum Ultimate Tensile Strength is 836.12 N/mm^2 obtained as compare to at 30 minute and 90 minute. The value of hardness is maximum at 350 °C and 90 minute is 250 BHN obtained as compare to at 30 minute and 60 minute.

Conclusion

- An increase of austempering time up to one hour resulted in an increase in tensile strength; however, it decreased when the time was increased.
- The maximum pearlite percentage achieved was 97.95 and 97.89 by austenizing at 850 ˚C and austempered at 250 ˚C at 60 minute and 90 minute respectively.
- The maximum value of tensile strength achieved was 1169.38 N/mm^2 and 1137.98 N/mm^2 by austenizing at 850 ˚C and austempered at 250 ˚C at 60 minute and 90 minute respectively.
- Austempering at 250 ˚C produced higher tensile strength as compare to austempering at 300 ˚C and 350 °C which resulted in lower tensile strength in all samples.

Continue...

- The maximum value of hardness achieved was 347 BHN and 341BHN by austenizing at 850 ˚C and austempered at 250 ˚C at 30 minute and 90 minute respectively.
- With the application of austempering process, the tensile strength was doubled. The value of tensile strength without any heat treatment was 495.2 N/mm2and when the samples were subjected to austempering heat treatment at 250 ˚C for one hour; it was increased to a value 1169.38 N/mm2.
- There was almost no effect of heat treatment on nodularity of the ductile iron. Good nodularity i.e. 81 % to 88 % was achieved with a good selection of charge and careful melting techniques.
- With the application of austempering process, the hardness was increase. The value of hardness without any heat treatment was 166 BHN and when the samples were subjected to austempering heat treatment at 250 ˚C for half hour; it was increased to a value 347 BHN.

Future Work

- More research is needed to ascertain the effect of other lone rare earth elements such as Cerium.
- More research is needed to ascertain the effect of austempering on microstructure and wear properties.
- Further work is necessary to establish the effect of multiple alloying elements on the properties of ductile iron.
- Validation of the work through simulation and analysis is necessary.
- Repeatability of the work should be investigated in further enhancement of the work.
- Different mathematical methods should be used for the same study to enhance working environment understanding which ultimately useful for further improvement.

Thank you...