Effect of Tempering Temperature and Time on Strength and Hardness of Ductile Cast Iron

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ABSTRACT. The effects of tempering temperature and time on the mechanical properties of ductile cast iron is investigated in the current work. The specimens were austenitized at 900°C for 120 minutes and then quenched in mineral oil at room temperature. Immediately after quenching the specimens were tempered at 400°C and 200°C for 60min, 90min, and 120min. In the tempering temperature range of 200°C-400°C, there is sudden increase in impact strength, ductility and toughness of the materials, as the temperature and time increase. The UTS drops initially, and hardness of materials will depends on amount of phase of martensitic and retained austenitic and graphite nodules. In this work alloying elements also effected the microstructure of the specimen. And due to increase tempering time the amount of martensitic phase will decrease and retained austenitic phase will increase, retained austenitic phase is softer then martensitic so hardness will decrease.

Keywords: Ductile Cast Iron, Tempering, Temperature, Time, Graphite Nodules, Retained Austenitic, Martensitic, ferrite phase,

1. Introduction

The mechanical properties of ductile irons are controlled by the amount of matrix phase and distribution of those phase and there microstructure [1]. They can be improved the mechanical properties through proper heat treatment application. Ductile Iron and steel are superficially similar, due to high carbon and silicon levels in ductile iron result in important differences in their response to heat treatment [2]. 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 [2]. Tempered ductile iron has excellent mechanical properties such as tempering reduces the strength and hardness and increases the ductility, toughness and machinability of quenched or normalized ductile Iron. In addition, tempering quenched castings also reduces residual stresses, decreases the amount of retained austenite, and reduces the probability of cracking. Oil quenching at 80°C-100°C to prefer to avoid cracks [3]. At if tempering temperature range of 400°C- 500°C, there is a sudden increase in impact strength and elongation %, but ultimate tensile strength and yield stress decrease [3]. In the relatively newly developed ductile cast irons (DI) with dual matrix structure (DMS), the structure consists of ferrite and martensitic or ausferrite (bainitic ferrite and austenite) [4]. In some components, suspension parts of automobiles, good toughness
and high ductility are required. These requirements are met by this newly developed iron that best exhibits tensile strength and proof strengths, together with hardness. It has been shown that the tensile strength and ductility can satisfactorily be optimized by critical combinations of austenitizing and tempering temperature and time [5]. Tempering is one of the most important heat treatment processes that is applied to quenched steel and cast iron. The objectives of this process include reducing the brittleness of materials, improvement of toughness and ductility, and also, reducing the probability of quench cracking and minimize stresses. Tempered hardness depends on as-quenched hardness level, alloy content and tempering temperature, as well as time. Okabayashi whose results indicate that impact strength of the samples, tempered at 600°C for 20 min, is better than those tempered at 200°C for 60 Minutes [6]. About effect of mechanical properties due to change in tempering temperature with a time variations. But for better mechanical properties amount of alloying is also a very important. Mg and Ce help to produced nodules in ductile cast iron [7]. As like carbon is to increase the volume of graphite produced which is turn reduce tensile strength, elongation and hardness and Si & Ni will increase the strength properties. Matrix structure of this type of ductile cast iron consists of a soft phase austenitic and a hard phase martensitic that are formed by a special heat treatment process [8]. The past results reported are mainly leaned towards Tempered ductile iron & the studies were focused on the effect of tempering temperature and time on mechanical properties. Hence the present investigation is concentrated to study the mechanical properties of tempered ductile iron compared with higher tempering temperature and different time.

2 Experiment

2.1: Specimen Preparation

In order to investigate the structure-property relationship, ductile iron test blocks with different alloying elements were brought from L&T Kansbahal, India. The chemical composition of test block by weight percentage is presented in Table 1. In order to carry out the experiment specimens were machined from the test blocks. Specimens were then austenitized at 900°C for 120 minutes and then it was quenched in mineral oil at room temperature. Immediately after quenching tempering heat treatment processes was done at 400°C and 200°C for 60 min, 90 min, and 120 min respectively. After heat treatment oxide layer from each of the specimen was removed by conventional filing & emery paper polishing and cloth and diamond polishing method and etched 2% nital.

| Elements | Wt. % |
|----------|-------|
| C        | 3.52  |
| Si       | 2.04  |
| Mn       | 0.17  |
| S        | 0.008 |
| Mg       | 0.042 |
| P        | 0.024 |
| Cr       | 0.02  |
| Ni       | 0.15  |
| Mo       | 0.001 |
| Cu       | 0.02  |
| Ce       | 0.007 |
| Fe       | Balance |
2.2: Tensile strength
Tensile test were carried out according to ASTM (A 370-2002) Test were conducted by using Instron 1195 universal testing machine connected to computer to draw the stress-strain curve accounting to tensile strength, tensile load of 50KN applied to the specimen up to the breaking point. Specimen have specific measurement of each sample. After failure we obtained tensile strength of different sample and stress-strain curve at different time and temperature.

2.3: Hardness testing
The method utilized for hardness testing was Vickers hardness testing. Vickers hardness was measured by applying a load of 20Kg & dwell time being 10seconds on each heat treated tempered specimen. Two diagonals, d¹ and d², are measured, take averaged and the surface area calculated then divided into the load applied.

2.4: Microstructural & nodules and nodularity Investigation
Specimens were first polished with belt polisher then followed by 1/0, 2/0, 3/0, 4/0 grades of emery paper & finally cloth polishing was done with alumina slurry followed by diamond polishing. Then etched 2% nital. Metallographic images were taken with the help of computer integrated optical microscope at 200X magnification. Before etched taken metallographic images thought optical microscope and investigate number of nodules present in the 1mm² area and calculate nodularity thought the computer software.

2.5: Impact energy
Charpy V-notch test described in ASTM E23 was for impact testing. The Charpy specimen was placed horizontally across supports with the notch away from the hammer. The indicator pointer was slide to the left until it indicates the maximum energy range on the upper Charpy- Tension scale. The pendulum arm was raised to the right until it is firmly supported by the latching mechanism. The pendulum was released by pushing up on the release knob. The hammer dropped, striking the specimen, with a swing through dependent on the amount of energy absorbed by the test specimen. The indicator moved and stopped when peak swing through was registered, providing a direct reading of the energy absorbed by the specimen. The indicated value from charpy scale was recorded.

2.6: Fractographic Investigation
Fracture surface of the sample after tensile test are analyzed by scanning Electron microscopy (SEM). First cleaned with acetone and properly handle, so that the fracture surface does not get damaged. Thereafter the specimen is cut to appropriate size for analysis using SEM (Scanning Electron Microscope.) Then all the specimens are kept under SEM for analysis of fracture surface. A series of photographs are taken in due course of experiment which helps in determining the type of fracture that has taken place.

3: Result and discussion
The effect of tempering temperature and time on different mechanical properties of ductile cast iron. as like yield stress, ultimate tensile strength, impact strength and elongation percentage are demonstrated in figure 1 and table 2. The mechanical properties vary with the Different matrix phase. when tempering time increase retained austenite decrease and reduces the probability of cracking, and ductility again increase with time the increase in strength initially at low time interval is due to the high amount of martensite and unreacted austenite, but the time increase above 30 Minutes the stage reaction in the intercellular regions for which strength decreases and ductility increases, Elongation of sample increases with increasing time,
and yield strength, tensile strength decreases with the increase in tempering time, and impact strength increases in tempering process because of increase in the toughness of the sample. And at higher austenitizing temperatures increase the carbon content of the austenite but the bulk hardness is reduced to retained austenite and a lower resultant martensite content [2]. Hardness decrease as the tempering temperature and time will increase. This is due to transformation of martensitic to retained Austenite phase, and retained Austenite phase in softer then the martensitic phase.

![Figure 1](image1.png)

**Figure 1** Effect of tempering Time On Elongation %, Impact Strength, Tensile Strength, Yield Strength

The drop in hardness accompanying secondary graphitization produces a corresponding reduction in tensile and fatigue strength as well as because alloy content affects the rate of secondary graphitization, each alloy will have a unique range of useful tempering temperatures [10].
The microstructures of respective specimens were shown in Fig.2 and this microstructure have different matrix phase, tempered ductile Cast Iron have nodules graphite structure and they have also austenite and martensitic phase[9]. The nodularization amount and graphite shape have a great effect on the workability [11]. In microstructures At 200°C have different amount of phase in table 3. at after austenitized temperature sample immediately quench in mineral oil at room temperature then at quenching martensitic transformation occurs and retained austenite formed, that amount of matrix define the mechanical properties of ductile cast Iron.

| Tempered sample | 0.2% Y.S. (MPa) | Tensile strength (MPa) | % Elongation | Impact strength (J/Cm²) | Hardness |
|-----------------|-----------------|------------------------|--------------|------------------------|----------|
| 200°C At 60 Min | 216.6           | 600.5                  | 9.59         | 8.80                   | 380HV20  |
| 200C At 90 Min  | 149.3           | 452                    | 9.92         | 10.21                  | 337HV20  |
| 200°C At 120 Min| 145.1           | 410                    | 13.21        | 11.33                  | 321HV20  |
| 400°C At 60 Min | 236.6           | 573.2                  | 8.34         | 11.43                  | 326.3HV20|
| 400°C At 90 Min | 223.1           | 518.4                  | 10.65        | 16.55                  | 278.5HV20|
| 400°C At 120 Min| 147.8           | 492.7                  | 14.32        | 18.65                  | 250.3HV20|

Table 2. Mechanical properties of tempered specimen at 200°C and 400°C at different time

| Tempering Temperature &Time | %of Martensitic | %of retained Austenite | % of Graphite | % of Ferrite |
|-----------------------------|-----------------|------------------------|--------------|-------------|
| 200°C at 60 Min             | 37.06%          | 45.03%                 | 17.90%       |             |
| 200°C at 90 Min             | 35.28%          | 45.86%                 | 18.85%       |             |
| 200°C at 120 Min            | 27.58%          | 55.47%                 | 16.94%       |             |
| 400°C at 60 Min             | 39.64%          |                        | 16.32%       | 44.03%      |
| 400°C at 90 Min             | 27.28%          |                        | 18.28%       | 54.42%      |
| 400°C at 120 Min            | 19.90%          |                        | 17.75%       | 62.34%      |

Table 3. Amount of matrix presence in tempered specimen at different time and temperature

Amount of matrix presence in tempered specimen is calculated by microstructure of different specimen we taken 10 different Images of same sample and calculate the threshold value of all Images and calculate area friction from microstructure analysis and take average value of different phases. at 200°C austenite phase not stable that we called retained Austenite and % of retained austenite is because after quenching we suddenly tempered the sample at 200°C therefore martensite transformation is not happened proper,
Figure 2.a Microstructure of 200°C tempered specimen at 60 Min

Figure 2.b Microstructure of 200°C tempered specimen at 90 Min

Figure 2.c Microstructure of 200°C tempered specimen at 120 Min

Figure 2.d Microstructure of 400°C tempered specimen at 60 Min
The morphology of the fracture specimens are analyzed by Scanning Electron Microscopy. Figure 3 show the fracture surface of different sample Specimens tempered at 200°C were dominant by brittle failure mode characterized by the presence flat shiny surfaces. Whereas with increase in tempering time shallow dimples were also observed in every specimens & were increased in the specimen tempered for 120 minutes. On the other hand specimens tempered at 400°C for various times showed dimples around the spherical nodules suggesting dominating nature of ductile failure mode. However the specimen tempered for 90 minutes showed mixed mode of failure characterized by presence of flat shiny surfaces along with dimples. On the other hand specimen tempered for 120 minutes showed complete ductile mode of failure.
Figure 3: Fractography Image of tempered specimen  
  a) at 200°C in 60 min  
  b) at 200°C in 90 min  
  c) at 200°C in 120 min  
  d) at 400°C in 60 min  
  e) at 400°C in 90 min  
  f) at 400°C in 120 min
4. Conclusion

The result obtained from present work can be summarized in the following points.
1. By increase tempering time martensitic content reduced resulting in increase of ductility and reduction of ultimate tensile strength and yield strength,
2. Within the temperature range of 200°C–400°C, there is a sudden increase in impact strength and elongation percentage, whereas within the same temperature range, the ultimate tensile strength and yield stress decreased.
3. Longer duration of tempering period at 200°C & 400°C increases the elongation percentage for tempering periods up to 120 min, and ductility increases
4. Whereas with increase in tempering time light pits were also observed in every specimens & were increased in the specimen tempered for 120 minutes. On the other hand specimens tempered at 400°C for various times showed pits around the spherical nodules suggesting dominating nature of ductile failure mode
5. As the tempering temperature & time increases the impact energy increases, this means the energy absorption capacity of Spheroidal graphite iron increases as the time & temperature of tempering increases.
6. Stress relieving, a low-temperature treatment, to reduce or relieve internal stresses remaining after quenching.
7. Oil is preferred as a quenching medium to minimize stresses and quench cracking, then the water or brine.
8. The nodularization amount and graphite shape have a great effect on the workability.

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