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Effect of Heat Treatment Procedures on Microstructure and Mechanical Properties on Nodular Iron

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Abstract: In their bid to produce cast iron latter than Malleable Iron, the scientist discovered the ductile iron or S.G. Iron (spherodial Graphite iron) way back in 1948.The use of this type of cast iron as an engineering material has been increasing day by day ever since its discovery. It is now replacing steel in many important engineering applications. The production of S.G Iron increased to a large extent during last two decades. The excellent combination of mechanical properties obtained in S.G. iron can further be informed by the heat treatment. The most recent development in this regard is the production of Austempered Ductile Iron (ADI). It provides an excellent combination of high tensile strength, wear resistance along with good corrosion resistance and quite significant amount of ductility. Due to these factors, S.G. or ductile iron are austempered when a very favourable combination of various properties is required. But this type of treatment is bit tricky, since it requires controlled heating and isothermal holding of the material. So it is necessary to find some attractive methods for property development in S.G. iron. In the present work conventional heat treatment proceeds like annealing, normalizing and tempering of the material has been performed. The mechanical properties obtain by various technique have been compared to one another. In this work two different grades of S.G. Iron (one with copper and another without copper) have been used. The effect of the alloying element (i.e., copper) has also been studied.

Keywords: Surface Roughness, CNC turning, MMR, Taguchi method, Noise Radius, Minitab, Machining Force.

1. Introduction:

There are many heat treatment procedures, each relying on the selection of temperature, holding time, heating and cooling rate. These heat treatment parameters govern the diffusion of element in the material and play an important role in altering the properties of the steel. Thus, the first sub-chapter describes the common diffusion process in steels with a relevant diffusion data of some elements. The common heat treatment procedures that are used in the making of tool steels are homogenisation, normalising, step annealing, stress relieving, soft annealing, hardening and tempering. Each has a specific purpose and is considered a critical part in the manufacturing chain of tool steels. In spite of the progress achieved during the first half of 20^{th} century in the development of Gray and malleable Irons, foundry men continued to search for the ideal cast iron – an as cast "gray iron" with mechanical properties equal to superior to Mellable Iron. J.W. Bolten speaking at the 1943 convention of the American Foundrymen's Society (AFS), made the following statement. "Your indulengence is requested to permit the posing of one question. Will real control of graphite shape be realized gray iron? Visualization a material, processing (as cast) graphite flakes or grouping resembling those of mellable iron instead of elongated flakes." Annealing, sometimes referred to as full annealing, is necessary for castings which are carbide as – cast. The samples are hold at a temperature of 900^{o}C for 2hours and one additional hour per inch section thickness. Then, cool to 700^{o}C and hold there for 5 hrs. Finally, cool at a maximum rate of 110^{o}C per hour to 480^{o}C, then air cool.

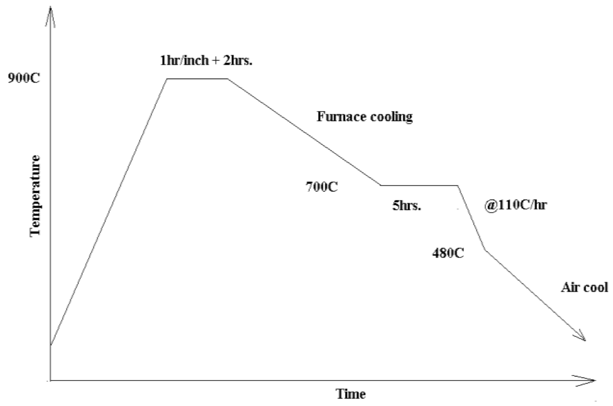

Fig 1: Annealing heat treatment

2. Literature Review:

A literature review is a summary of a subject field that supports the identification of specific research questions. A literature review needs to draw on and evaluate a range of different types of sources including academic and professional journal articles, books, and web-based resources.**Wanhui Huang and Liping Lei et.al.(2023),**a strategy combining intercritical quenching, pre-tempering, and tempering processes was implemented to optimize the microstructures and mechanical properties of 5CrNiMoV steel. By intercritically quenching at 1050 °C, pr-tempering at 600 °C, and tempering at 550 °C, the steel exhibited a comprehensive performance with a yield strength of 1120 MPa, an ultimate tensile strength of 1230 MPa, and an elongation of 8.2%. [1] **Madhusudan Baghelet. al. (2022)**A modified stir casting method was used to fabricate novel Al6082 composites reinforced with 0, 0.3, 0.6, 0.9, and 1.2 wt% of multiwalled carbon nanotubes (MWCNTs). A field emission scanning electron microscope was used to examine the microstructure, while elemental evaluation was performed with an energy dispersive X-ray spectrometer.

MWCNTs/Al6082 composites were subjected to a heat treatment cycle (T6) to enhance their mechanical strength. Mechanical alloying and ultrasonication enhanced the wettability during fabrication resulting in the uniform distribution of MWCNTs up to 0.9 wt%.[2]**O.O. Agboola et.al (2020)**Quenching is one of the major processes of heat treatment of medium carbon steel that aims at improving its mechanical properties. However, the effectiveness of this process is dependent on several control factors that must be maximized to obtain optimum results in terms of hardness, yield strength, ultimate tensile strength among others. This study aims at optimizing the process of improving the mechanical properties of medium carbon steel by varying some key factors like the quenchant used (A), heat treatment temperature (B), and soaking time (C). The measured responses in this study were the hardness, yield strength (YS), and ultimate tensile strength (UTS). [3]

Roman kuziak et.al (2019) The paper presents metallurgically based approach allowing the design of the parameters of the pearlitic rail head heat treatment to obtain the targeted mechanical properties. The described solutions enable predicting the progress of phase transformations, final microstructure and mechanical properties distribution in the pearlitic rail subject to heat treatment. It also allows the optimization of the cooling conditions to obtain a strictly defined distribution of mechanical properties in the rail head. The program is developed as a result of research activities performed in the HyPremRail R&D project. The core of the program consists of the phase transformations model which is implemented in the numerical code based on the FEM for heat transfer calculations.[4] **Ananda Hegde et. al (2019)** Austempered Ductile Iron (ADI) belongs to the family of cast irons whose mechanical properties are altered using austempering heat treatment process. The objective of this paper is to study the effects of heat treatment parameters on manganese alloyed ADI. Hence, austenitization temperature, austempering temperature and austempering time are taken as the control variables along with the manganese content in the material. The effects of heat treatment are studied by measuring the ultimate tensile strength and the hardness of the material. The regression equations are developed to relate the various parameters under study. [5]

Sunpreet Singh et. al. (2019) Fused filament fabrication (FFF), an economic additive manufacturing (AM) method, is largely used for the fabrication of customized components (of medical, engineering, architectural, toy, artistic, etc. industries). However, the poor mechanical and surface properties are critical barriers limiting the growth of FFF. Therefore, a novel heat treatment approach has been utilized to improve the overall performance of printed parts. The parts were made with acrylonitrile-butadiene-styrene (ABS) with three infill densities (20, 60, and 100%) and annealing was carried out by changing the levels of temperature (105, 115, and 125 °C) and time duration (20, 25, and 30 min).[6]**MP Prabhakaran et. al. (2019)**In this investigation, laser welding process parameters have been optimized for austenitic stainless steel (AISI316) and low carbon steel (AISI1018) materials by using Taguchi based grey relational analysis. Butt joint trials were carried out using 3.5 kW diffusion-cooled slab CO_2 laser by varying laser power, welding speed, and focal distance. The optimum parameters have been derived by considering the responses such as tensile strength and microhardness. The optimal parameters are laser power 2600 W, welding speed 1.5 m/min and focal distance 20 mm. [7]

M. Araghchi et. al. (2018) Residual stresses induced during quenching of aluminum alloys cause dimensional instability and distortion. In this study, the effects of different concentrations of polyalkylene glycol (PAG) quenchants on residual stresses and mechanical properties of 2024 aluminum alloy were investigated. Surface residual stresses were measured by using hole-drilling strain-gauge method. Also, mechanical properties and microstructure of the heat-treated samples were analyzed using hardness measurements, tensile tests, and transmission electron microscopy. Results showed that quenching into a 15% polymeric solution and aging at 190 °C for 12 h cause 50% reduction in residual stress as compared with quenching in water at 20 °C and naturally aging. Moreover, tensile strength decreased by 104 MPa (~ 20%) in compared with the T6 sample.[8]

StefaniaToschi (2018) The aim of the present work is the study of T6 heat treatment of A354 (Al-Si-Cu-Mg) casting alloy. The heat treatment was optimized by maximizing mechanical strength of the alloy while keeping the treatment cost effective, reducing treatment time and temperature. Due to the presence of low melting compounds, a double stage solution treatment was proposed. The first stage was aimed at the homogenization and dissolution of the low melting phase while a second stage at a higher temperature was evaluated to foster dissolution of Cu/Mg rich intermetallics and keep the solution time and temperature as low as possible.[9]

2,1Research Objectives:

The objective of this work is to determine the mechanical properties and microstructure of heat-treated ductile iron with two different grades. One is with Cu and other is without Cu. After that compare these properties with different treatment conditions, the treatment conditions are mainly tempering at different temperature and austempering at constant temperature and variation of time. Mechanical properties are:

1. Tensile strength (U.T.S., 0.2% elongation),
2. % Elongation,

Then these mechanical properties are related with microstructure and fracture surfaces of the different samples after treatment

3. Experimental Procedure:

Ductile iron produced in a commercial foundry known as L&T kansbahal, has been used for these experiments. Two grades of ductile iron were used. The differences between these two grades were: one contains copper, while other was without copper.They were designated as Grade A and Grade B. Chemical compositions of raw material obtained by weight chemical analysis method used in this study are given in Table 1.

Table 3.1: Chemical Composition in %

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All are in wt %	C	Si	Mn	Cr	Ni	Mg	Cu	S	P
Grade A	3.55	2.1	0.18	0.03	0.12	0.038	0.41	0.009	0.024
Grade B	3.57	2.22	0.23	0.03	0.42	0.045	....	0.011	0.026

For different tests the solid block of ductile iron was cut to thickness of 4-6 mm using power hacksaw. Then they are grinded, polished and machined to the dimension required for various experiments to be carried out. Twenty samples from each grade were taken in a group. To homogenize the samples kept them in a muffle furnace for one hour at 927^0 C, some samples were conventionally treated and some were austempered for different times with constant temperature. After austenization for annealing samples were cooled in furnace for 12hrs and normalizing was done by rapid cooling of samples in still air for 30 minutes.

Fig-2 Tensile Testing Machine

Result and Discussion: The mechanical properties measured by using Instron1195 and dimensions of specimen was carried out according to ASTM (A 370-2002), are given in Table-1.

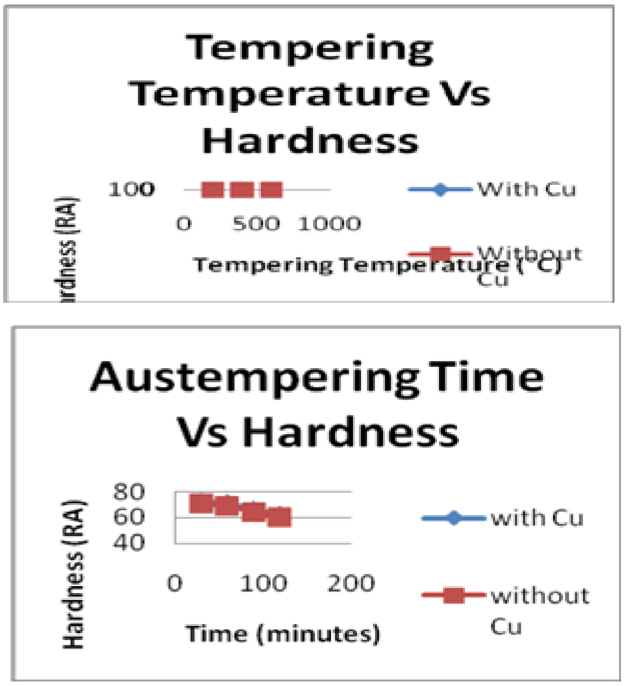
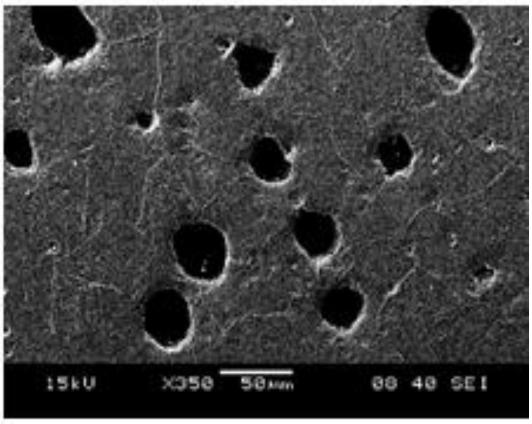
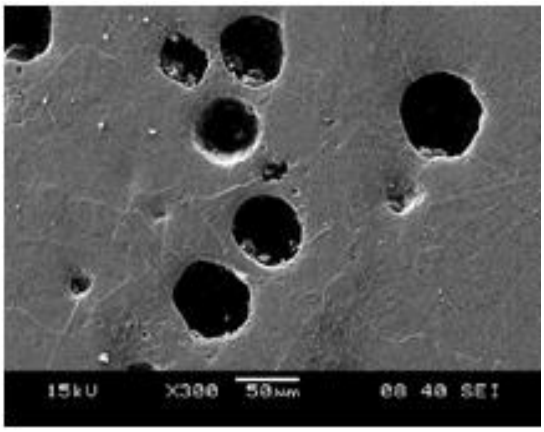


Fig 3: Variation of hardness with tempering temperature and austempering time.

lists the mechanical properties viz. Tensile strength, 0.2% Proof stress, % Elongation, Hardness etc. of cast irons (with and without Cu addition) respectively.



(a)Annealed (Gd A)



(b) Annealed (Gd B)

Figure 4 Layout structure

Conclusion: The correlation between the microstructures and mechanical properties of Ductile Iron were studied along with their fracture surfaces for two different heat treatment processes- Quenching and Tempering; and Austempering. We also studied the effect of copper on the microstructures, mechanical properties and fracture surfaces after heat treating.

- As the tempering temperature increases, ductility of the samples also increased but compromising with hardness and strength.
- The strength and hardness values were more for the sample with copper while ductility was found to be more for the sample without copper.
- The fracture surfaces showed a mixed mode of fracture for both the grades of samples. But, the percentage of dimple fracture was found to increase with tempering temperature.

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