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Research paper

The Effects of Austempered and Quenched & Tempered on Mechanical Properties of Alloyed Grey Cast Iron

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Abstract

In this study, the effects of austempered and quenched & tempered on mechanical properties of grey cast iron with and without the addition of niobium were investigated. The austempering heat treatment started by heating the samples to an austenitizing temperature of 900°C with a soaking time of 90 minutes before quenched in salt bath furnace with a temperature of 360°C and hold for 180 minutes before it been cooled down to room temperature. The quench and tempering process started with heating the samples at 910°C and hold for 33 minutes. Then the samples are quenched by using engine oil before being heated up again to temperature of 400°C with soak time up to 17 minutes before allow it to be cooled at room temperature. The tests conducted include hardness, tensile and impact test. The microstructure of the samples was observed using optical microscope. The fracture surface of the test tensile and impact specimens was analyzed by using S.E.M. observation. The hardness of the as-cast, austempered and quenched & tempered alloyed grey cast iron are higher compared to the hardness of pure grey cast iron. By addition of Niobium, the tensile strength of the grey cast iron increased by 67.49 % compared to pure grey iron. Tensile strength and elongation of the alloyed grey cast iron slightly increased after heat treated. Austempered alloyed grey cast iron resulted the highest value of impact toughness (6.5 J) compared to other specimens. This showed that austempered alloy grey cast iron is the best in absorbing the energy subjected to it.

Keywords: *Austempered Grey Iron; Fractography; Mechanical Properties; Quenching and Tempering.*

1. Introduction

Cast iron is a material that is primarily used in a lot of heavy-duty industrial applications that include the aerospace, automotive and agricultural due to the lower cost compared to other materials [1]. The three general types of cast irons are grey, white and nodular cast irons. Grey cast iron gets its popularity due to high compressive strength, high resistance to deformation, resistance to oxidation and low in melting point. A high number of researches have been conducted through the years in order to further improve the properties of grey cast iron. The properties of grey cast iron can be increased through the process of adding alloying elements and proper heat treatments.

The terms grey and white refers to the characteristics appearances of the fractures of grey and white cast irons. As for nodular, it is a descriptive of the shape of the graphite particles in nodular cast irons. For grey cast iron, as the graphite forms, it produces flakes with sharp points within the iron matrix (cast iron) that leads to stress concentration.

The addition of niobium alloy changed the properties of grey cast iron. The hardness and wear resistance of grey cast iron improved with the added niobium alloy [2]. The wear properties of grey cast iron mostly are depending on the nature of the niobium-rich hard phase that distributed homogeneously and strongly bonded with the matrix.

Heat treatment is used to change the mechanical properties of alloys and castings as they are structure-sensitive. Austempered grey cast iron is an important improvement of grey cast iron in order to increase the mechanical properties [3]. Austempered grey cast iron is obtained through the austempering heat treatment process. According to research conducted by H. Mohrbacher, the austempered grey cast iron is employed as the conventional heat treatment process resulted in unacceptable cracking [4]. According to Cheng- Hsun Hsu et.al [5], the fracture toughness of austempered grey cast iron is improved compare to pure grey cast iron since it is a brittle metallic material.

In quenched & tempered grey cast iron, carbon is generated during the tempering process. After grey cast iron is heated up to an austenitizing temperature for a certain amount of time, they are immediately quenched in quenching medium. This is to obtain the martensite structure that can only be produced during rapid cooling. After quenching, specimens are reheated up to a tempering temperature to produce the structure of tempered martensite. In a research conducted by Balachandran, the optimum tempering temperature that be used is 400°C [1].

Together with the good properties of grey cast iron, there are some disadvantages in using this material in some applications. Grey cast iron brings a low tensile strength that makes it a poor shock resistor. Also, grey cast iron can be too brittle for some applications and cause failure [6]. Grey cast iron is very bad of impact resistance and it can be said as non-existent. The ductility of grey cast iron is quite low compared to other material and it can be improved through proper heat treatment method. Therefore, this research is focus on improving the mechanical properties of grey cast iron with the addition of 0.32% niobium alloy together with austempering and quenching & tempering heat treatments.

2. Experimental Procedure

2.1. Sample Preparation

The samples used for this study were prepared in form of double cylinder using CO2 sand casting process in a 60 kg capacity induction furnace. The mixture of pig iron, carburizer, and steel scrap were first melted until it reached the melting temperature of 1450°C before nodularization process and addition of 0.32wt% niobium as alloying elements. The chemical compositions of samples were obtained through spectrometer test and shown in Table 1.

2.2. Heat Treatment

After all the specimens are machined and prepared, heat treatments processes were conducted. There are two types of heat treatments conducted which are austempering and quenching & tempering. In the austempering process, the specimens are heated up to an austenitizing temperature of 900°C and soaked for 90 minutes. After that, the specimens are quenched in salt bath furnace at the austempering temperature of 360°C with a holding time of 180 minutes. The specimens were then cooled to room temperature. Fig. 1 shows the schematic diagram of the austempering heat treatment.

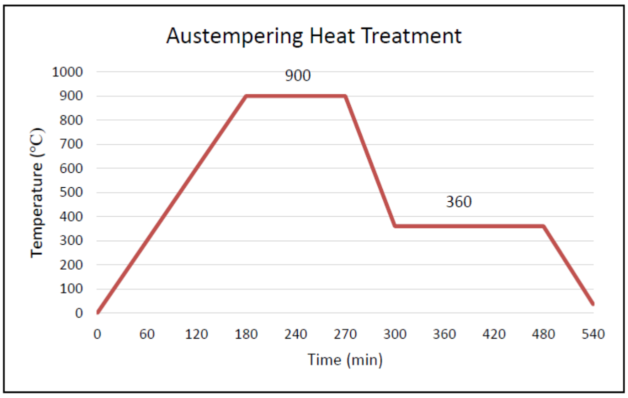


Fig. 1: Schematic diagram of austempering heat treatment

Another heat treatment conducted was the quenching and tempering. The process started by heating the specimens to an austenitizing temperature of 910°C with a soak time of 33 minutes. The process continued with quenching the specimens using engine oil before heating it up back to a tempering temperature of 400°C with a holding time of 17 minutes. The specimens were cooled to room temperature. Fig. 2 shows the schematic diagram of the heat treatment.

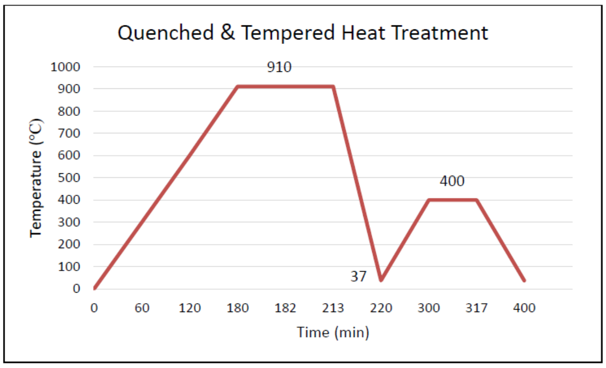


Fig. 2: Schematic diagram of quenched and tempered heat treatment

2.3. Mechanical Testing

Vickers hardness test were conducted to measure the resistance of the specimens to the deformation of a material. The standards followed for the Vickers hardness test is the ASTM E92 standard. The amount of load used in the test is 1000 N. 15 seconds are taken for the hardness test to complete and the diagonal value of the diamond is measured before the hardness value is automatically calculated. The process was repeated for 5 times to obtain the average value.

Tensile test was conducted to identify how the specimens react as force by pulling it in tension. The standard followed for the tensile test is ASTM E8M. To compare the properties, both pure and alloyed specimens were tested. The pulling rate is 2 mm/min and the tensile test stopped after the specimen broke.

Impact test was conducted to obtain the result of the amount of energy absorbed by the specimens during fracture. ASTM E23 standard was followed and the type of impact tester used is the Charpy impact tester machine.

2.4. Microstructure and Fracture Surface Observation

The samples needed to be cut, mounted, grinded, polished and etched. The specimens were grinded by using the sand papers with the following grades of 120, 180, 240, 320, 400, 600 and 1200. For the polish process, the polishing powders used are from the value of 9.5, 5, 3 and 1. After being polished, the specimens are etched with a 2% Nital solution before being observed by using the optical microscope.

Fracture surface observations are done after tensile and impact tests are being conducted. The purpose of the observation is to determine the cause of failure and to study the characteristics of the fractured structures after being tested. The observations started by preparing the specimens suitable to the features of the Scanning Electron Microscope (S.E.M.).

Table 1: The chemical composition of samples

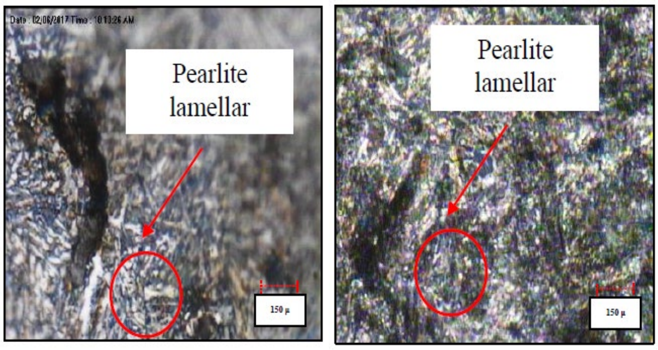
C	Si	Mn	P	S	Cr	Ni	Cu	Ti	Nb	V	Fe
2.56	2.24	0.488	0.0074	0.085	<0.015	2.24	0.32	0.027	0.32	0.019	<90.2

3. Results and Discussion

3.1. Microstructure Observation

Fig. 3 shows the microstructure of as-cast Niobium alloyed grey cast iron. From the microstructure below, the structure of ferrite can be detected. The use of ferrite to the grey cast iron is to form its magnetic properties. As Niobium alloy was added, it formed strong carbides in the matrix that tend to refine the grain size during the solidification process. The fine distribution of the strong carbides can increase the wear resistance of grey cast iron [7][8].

Fig. 3: The microstructure of an as-cast niobium alloyed grey cast iron



(a) **(b)**

Fig. 4: Microstructure of Austempered (a) Pure Grey Cast Iron (b) Niobium Alloyed Grey Cast Iron

The structure of ferrite, the pearlite lamellar structure also can be seen in the microstructure of grey cast iron. Fig. 4 (a) and (b) show the pearlite lamellar structure of austempered pure grey iron and alloyed grey cast iron. By comparing the two figures, the pearlite lamellar spacing in austempered alloyed grey cast iron is finer compared to austempered pure grey cast iron. The pearlite lamellar spacing was reduced due to the addition of Niobium alloying element. The higher the content of the alloying element, the lamellar spacing of pearlite were decreasing. The pearlite lamellar spacing is controlled by the austenite-to-pearlite transformation (eutectoid) temperature. A lower eutectoid temperature and a finer structure will be formed. The formation of pearlite lamellar is to improve its hardness properties [9].

Graphite flake (as shown in Fig. 5) affects the mechanical properties of grey cast iron. In grey cast iron, the graphite is in the shape of three-dimensional flake. The tips of the flakes act as pre-existing notches in where stresses concentrate and give it brittle manner. Graphite flakes give grey cast iron its machinability as it tends to crack easily across the graphite flakes [8].

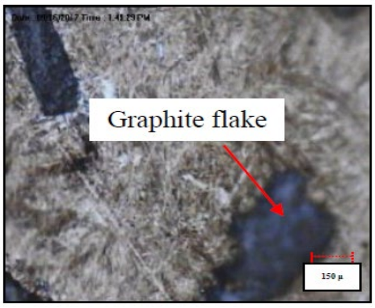


Fig. 5: The structure of graphite flake in grey cast iron

Martensite is produced when the material is immediately quenched after being heated up to an asutenitizing temperature. It happened as the rapid cooling process of the austenite makes the carbon atoms does not have time to diffuse out of the crystal structure [10]. The austenite transformed to martensite until the lower transformation temperature is reached. As the quenched specimens are heated back up to a tempering temperature, the martensite transformed itself to become tempered martensite. Tempering process increased the toughness of the iron-based material. Fig. 6 shows the structure of tempered martensite taken from the specimen that has been quenched and tempered [8].

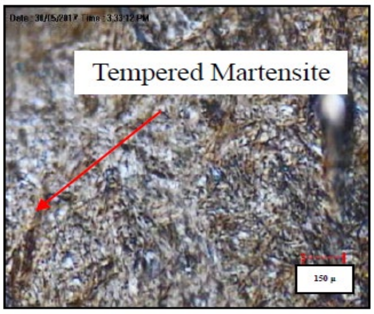


Fig. 6: Structure of tempered martensite

3.2. Hardness Test

Hardness is a type of measuring on how the material resist as a compressive force is applied by various kinds of permanent shape. The hardness of materials is depending on the ductility, elastic stiffness, plasticity, strain, strength, toughness and viscosity. In Fig. 7, it shows that hardness of various types of specimens. The highest hardness value (which is 465.08 HV) was obtained when the niobium alloyed grey cast iron undergoes the quenched and tempered heat treatment. Also, the hardness of austempered pure and alloyed grey cast iron were increased compared to as-cast pure and alloyed grey cast iron. Base on the hardness results obtained, it proved that heat treatments can increase the hardness of grey cast iron.

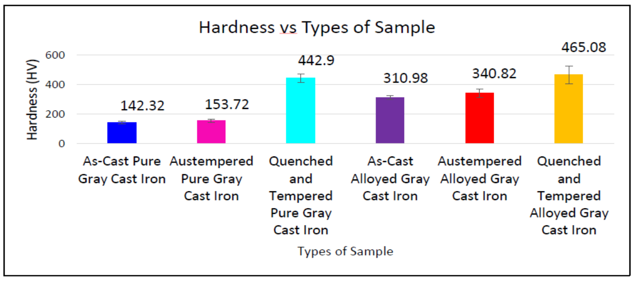


Fig. 7: Hardness of various types of specimens

3.3. Tensile Test

Referring to Fig. 8, the tensile strength of the Niobium alloyed grey cast iron was increased compared to as-cast pure grey cast iron. As 0.32% of Niobium alloy is added to grey cast iron, it increases the tensile strength from 165 MPa to 507.571 MPa. This phenomenon is due to properties of niobium which cause the ductility of the material increased. During the machining process of as-cast alloyed grey cast iron, the process stopped when the diameter of the gage length is 12 mm. The machining process was stopped to avoid the specimen from fracturing during the process. Therefore, the diameter for the as-cast alloyed grey cast iron is larger compared to other specimens. It will cause tensile strength of as-cast alloyed grey cast iron to be a bit higher compared to austempered alloyed.

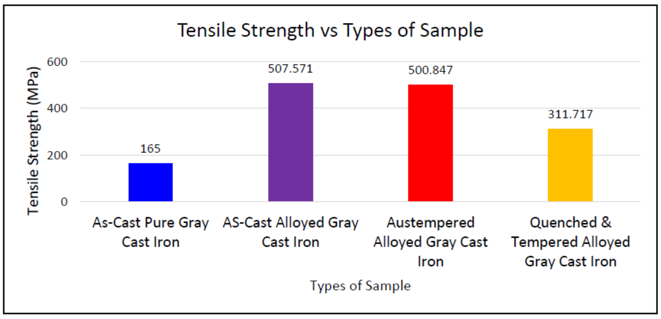


Fig. 8: Tensile strength of various types of specimens

Elongation can be defined as measurement of length in a sample's gage after fractured of the specimens. Referring to Fig. 9 and Fig. 10, it shows that the elongation of grey cast iron increase as niobium alloy is added. The elongation of the as-cast pure grey increased from 0.5 mm to 3.423 mm when 0.32% Niobium alloy is added. The elongation austempered alloyed grey iron has the highest value which is 3.707 mm. the elongation is slightly higher compared to as-cast alloyed grey cast iron. As the elongation of the specimen increased, it caused the ductility of the specimen to increase and the elasticity of the material improved [11].

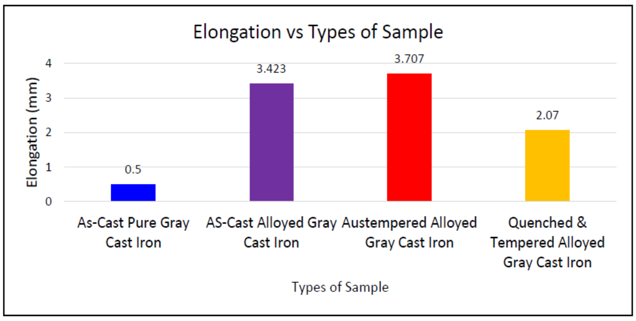


Fig. 9: Elongation of various types of specimens

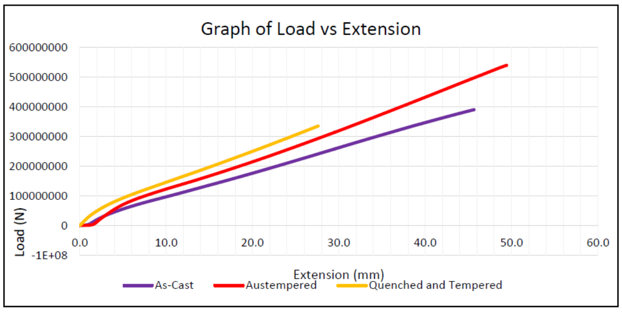


Fig. 10: Relationship between load and extension of different types of specimens

3.4. Impact Toughness

Fig. 11 shows that the austempered alloyed grey cast iron have the highest impact toughness compared to the other specimens. As the specimen being struck by the released pendulum, the scale will show the energy that the specimen absorbed. Higher value of impact toughness shows that the material can withstand a higher amount of energy as being struck. Even austempered alloyed grey cast iron have the highest impact toughness compare to other specimens, but the value of 6.5 J is considered to be very low compared to the amount of energy that the impact tester can provide. The impact tester can give an impact up to the value of 300 J.

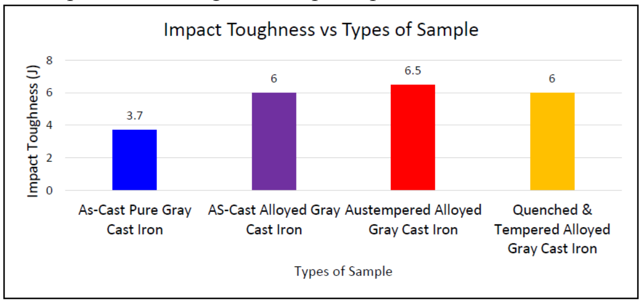


Fig 11: Impact toughness of different types of specimens

3.5. Fracture Surface Observation

Referring to Fig. 12, the patterns of the fracture shows fine faceted cleavage, cracking of single grain and river pattern. All these patterns proved that the material experienced brittle fracture. Brittle fractures propagate through the grains. For high strength material, the crack follows the grain boundaries. In a cleaving fracture, the separation of the material occurred along a well-defined crystallographic plane. During the cracking process, ferrite grains are cleaved in a way along the plane and as it reached the grain boundaries the crack stopped due to the existence of regions of austenite. A new crack nucleus needs to be formed. The grains crack in isolation from each other, then the separation of the grain boundary regions occurred after a certain yielding. These patterns explained why the fracture toughness is quite low for the materials tested [5].

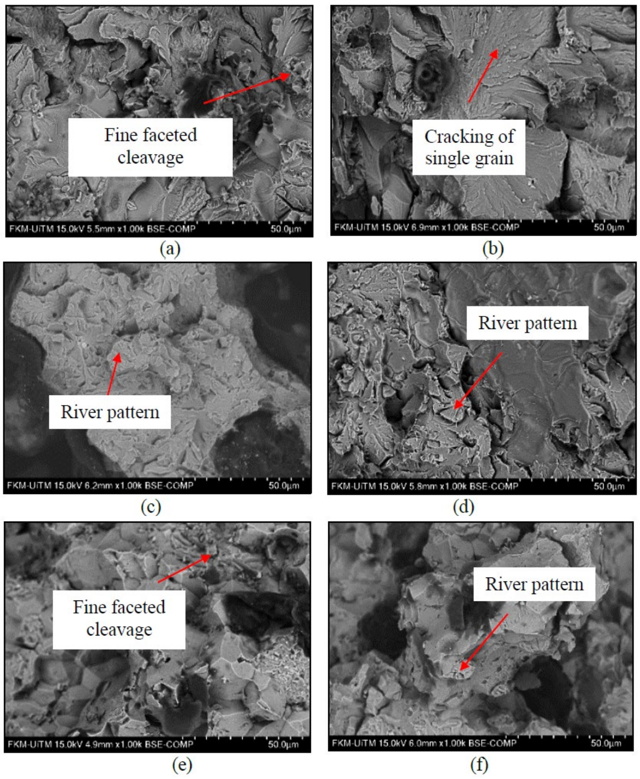


Fig 12: S.E.M. Observations at Magnification of x1000
(a) As-cast Alloyed (Tensile), (b) As-cast Alloyed (Impact)
(c) Austempered Alloyed (Tensile), (d) Austempered Alloyed (Impact)
(e) Q&T (Tensile), (f) Q&T (Impact)

4. Conclusion

From the results obtained, it can be concluded that the structure of graphite flakes in each specimen has been identified. This proved that the specimens are grey cast iron. By adding Niobium, the pearlite lamellar spacing is getting finer that changed the hardness properties of the material. Tempered martensite structure was formed through the immediate quenched process before being tempered to a tempering temperature. The hardness of the as-cast, austempered and quenched & tempered alloyed grey cast iron are higher compared to the hardness of pure grey cast iron after the same heat treatments are applied. The highest hardness is 465.08 HV which belong to quenched and tempered alloyed grey iron. As 0.32% of Niobium alloy is added to grey cast iron, it increases the tensile strength from 165 MPa to 507.571 MPa. In addition, the elongation of austempered Niobium alloyed grey cast iron has the highest elongation with a value 3.707 mm. This is caused by the properties of Niobium that increase the ductility of the material. The austempered alloyed grey cast iron shows the highest value of impact toughness (6.5 J) compared to other specimens. This showed that austempered alloy grey cast iron is the best in absorbing the energy subjected to it. Even with the highest value of impact toughness, the value is still too small compare to the energy that the impact tester can provide. The fracture surfaces after conducted tensile and impact test are observed by using Scanning Electron Microscope (S.E.M.). From the observation, it can be seen that incompletely melting of niobium alloy occurred

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