Journal of Physics: Conference Series

Effect of Austempering Holding Time Variations of 30, 60, and 90 Minutes at 300 °C on The Microstructure and Toughness of Nodular Cast Iron

To cite this article: A S Darmawan *et al* 2024 *J. Phys.: Conf. Ser.* **2739** 012029

Effect of Austempering Holding Time Variations of 30, 60, and 90 Minutes at 300 °C on The Microstructure and Toughness of Nodular Cast Iron

A S Darmawan[1*], A D Anggono[1], A Yulianto[1], B W Febriantoko[1], and A Hamid[2]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani, Tromol Pos 1 Pabelan, Surakarta 57162, Indonesia

[2]Technology Education Department, Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Johor Darul Ta'zim, Malaysia

* Agung.Darmawan@ums.ac.id

Abstract. The phases of the nodular cast iron matrix are similar to those of steel. Therefore, heat treatment of steel can be applied to nodular cast iron. A potential heat treatment for nodular cast iron is austempering. This study aimed to determine the effect of austempering holding time at 300 °C on the microstructure and toughness of nodular cast iron. The austempering process begins with austenitizing at a temperature of 850 °C for 60 minutes, then the quenching process is carried out in a salt bath until a temperature of 300 °C is held with variations of 30, 60, and 90 minutes, then cooled to room temperature. Metallographic testing was conducted to determine the phase change before and after the austempering process using a Scanning Electron Microscope (SEM). Meanwhile, impact testing was carried out to determine changes in toughness before and after the austempering process. At a holding time of 30 minutes, metallographic testing on the raw material produced a gray coarse pearlite phase, black nodular graphite surrounded by white ferrite. After the austempering process, gray fine pearlite and black nodular graphite appeared. At the holding time of 60 and 90 minutes, the graphite sizes were bigger. Austempering withholding times of 30, 60, and 90 minutes resulted in impact energy of 4.2, 10, and 11 Joule. From the results of the study, it was concluded that an increase in holding time would increase the size of the graphite and the toughness of nodular cast iron.
Keywords: *Austempering, Nodular Cast Iron, Toughness*

1. Introduction

In industrial applications, nodular cast iron material is a suitable material to be applied in the manufacture of various products. Nodular cast iron has the ability to be easily formed [1-6]. Nodular cast iron is a type of cast iron that contains graphite in the form of nodules. Nodules in nodular cast iron provide higher toughness, strength, fatigue resistance, stiffness, and vibration resistance than gray cast iron which contains graphite in the form of flakes. The excellent properties of nodular cast iron are due to its microstructure consisting of nodular graphite surrounded by ferrite and pearlite [7-13].

However, the toughness of nodular cast iron can still be improved by modifying the microstructure. The microstructure can be changed by adding alloying elements or by heat treatment [14-16]. One of the most common heat treatments applied to increase the toughness of nodular cast iron is austempering.

Austempering heat treatment leads to the formation of an ausferrite matrix and the resulting iron is called Austempered Ductile Iron [17-21].

The austempering process of cast iron alloys involves two steps. The first is austenitization, in which the ferrous alloy is heated to a certain temperature in the austenitizing range and maintained for some time to form an austenitic matrix (γ). The second is rapid cooling from the austenitizing temperature to a temperature range of 250 ºC - 400 ºC, which is maintained for some time until the austempering reaction is complete [22-24].

The strength of Austempered Ductile Iron depends on the structure of the ausferrite matrix, which depends on the austempering temperature. Increasing the strength of Austempered Ductile Iron by the austempering process reflects a decrease in the thickness of the component, thereby reducing its weight of the component. The ausferrite matrix with high strength and good toughness makes Austempered Ductile Iron more wear-resistant than other materials [25-29].

Toughness is an important mechanical property [30, 31]. Toughness is a material's ability to absorb energy and undergo plastic deformation without fracture. The purpose of this study is to investigate how austempering holding time variations of 30, 60, and 90 minutes at 300 ºC affect the microstructure and toughness of nodular cast iron.

2. Materials and Methods

The material used in this research was nodular cast iron. The composition of this nodular cast iron can be seen in Table 1.

Table 1. Nodular cast iron composition

Element	Weight %
C	3.4876
Si	2.6449
S	0.0105
P	0.0163
Mn	0.5748
Mg	0.0351
Ni	0.0117
Cr	0.0896
Mo	0.0026
Cu	1.1144
W	0.0034
Ti	0.0356
Sn	0.0088
Al	0.0130
Nb	0.0011
V	0.0048
Co	0.0034
Pb	0.0004
Ca	0.0344
Zn	0.0018
Fe	91.95

The medium used for the quenching process in austempering was Bath Salt. Bath Salt consists of a mixture of Sodium Nitrite ($NaNO_2$), Potassium Nitrate (KNO_3), and Sodium Nitrate ($NaNO_3$) in a ratio of 0.2: 0.3: 0.5 with a total weight of 300 g and added with 500 ml of water.

Prior to the austempering process, the raw material was first tested metallographically by Scanning Electron Microscopy (SEM) and tested for impact by the Charpy method based on ASTM E23 Standard. The heat treatment process was carried out by heating the specimen at 850 ºC with a holding time of 60 minutes for the austenitization process. Then the temperature was lowered rapidly by quenching method with bath salt media until the temperature becomes 300 ºC. The holding time of austempering varied from 30 minutes, 60 minutes, and 90 minutes. After that, it was cooled at room temperature in free air. After the cold specimens were subjected to metallographic tests with Scanning Electron Microscopy (SEM), and Impact tests.

3. Results And Discussions

Figure 1a shows the microstructure of the raw material of nodular cast iron. The visible microstructure consists of a black spherical graphite phase surrounded by a white ferrite phase. Pearlite is seen as an alternating light and dark lamellar phase [32, 33].

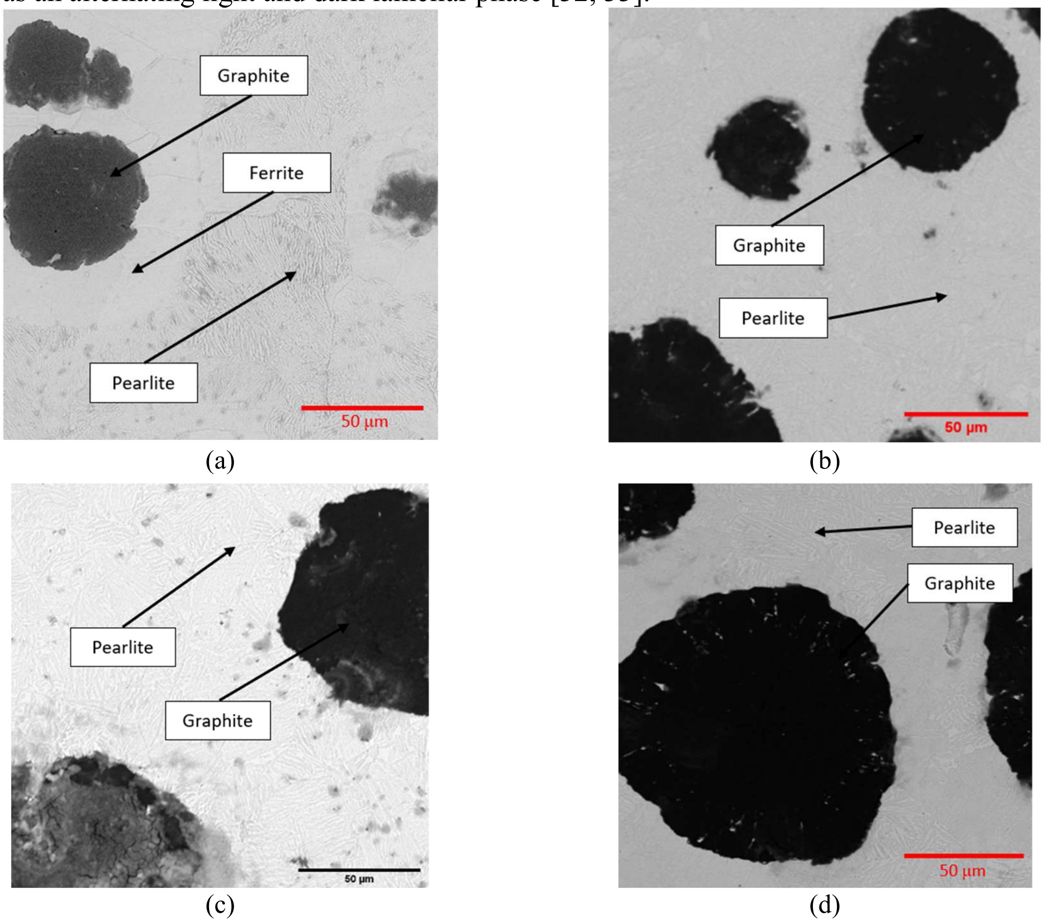

Figure 1. Microstructure of nodular cast iron metallographic test results with SEM (a) raw material (b) austempering holding time 30 minutes (c) austempering holding time 60 minutes (d) austempering holding time 90 minutes.

Figure 1b shows only the graphite and pearlite phases. There is no visible ferrite phase in the figure. This ferrite phase combines with free carbon to form the cementite phase. The cementite phase mixes with the ferrite phase to form the perlite phase. Figures 1c and 1d show that the graphite size increases with the longer austempering holding time. This means that the pearlite matrix size will decrease.

The effect of the austempering holding time is shown in Figure 2. The impact energy on the raw material is 5.1 joules. The austempering holding time of 30 minutes resulted in a decrease in impact energy by 17.6% to 4.2 Joules. The presence of more cementite phase results in an increase in the brittleness of the material which reduces the impact energy [34]. This means lowering the toughness of nodular cast iron. The austempering holding time of 60 minutes resulted in an increase in impact energy to 10 Joules. An increase in austempering holding time results in an increase in ferrite size and a decrease in pearlite so that the toughness becomes higher. The same trend is seen when the austempering holding time is increased to 90 minutes.

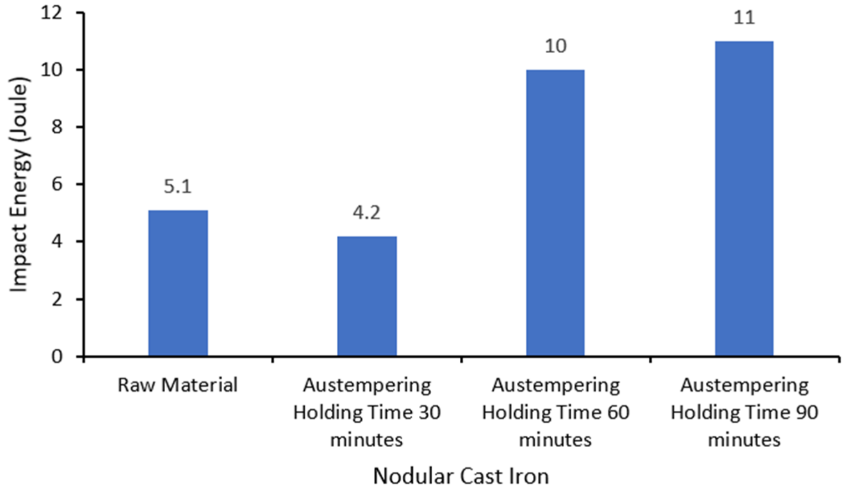

Figure 2. Effect of austempering holding time on impact energy.

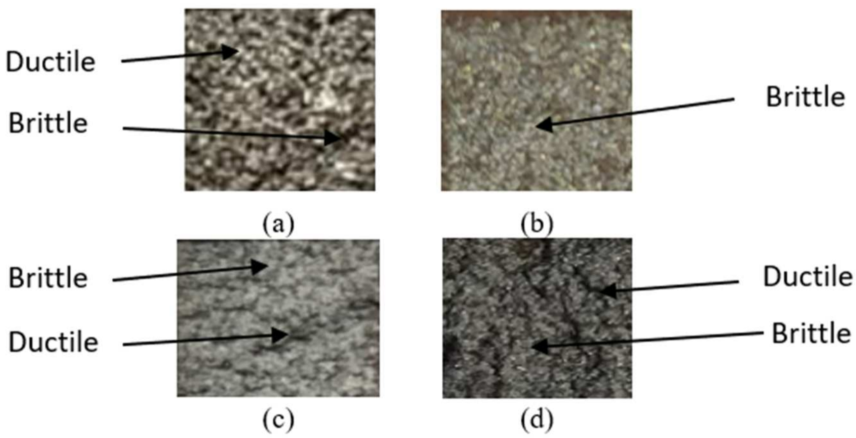

Figure 3. Fracture surface morphology of nodular cast iron due to impact testing (a) raw material (b) austempering holding time 30 minutes (c) austempering holding time 60 minutes (d) austempering holding time 90 minutes.

Figure 3 shows the fracture surface morphology of nodular cast iron due to impact testing. The fractured surface of the raw material (see Figure 3a) shows a mixture of flat and shiny surfaces and gloomy and fibrous surfaces. This indicates a mixed type of fracture between ductile fracture and brittle fracture. A flat and shiny fracture surface was seen in almost all surfaces of nodular cast iron which was austempered with a holding time of 30 minutes (see Figure 3b). The fracture surface of austempered nodular cast iron with a holding time of 60 minutes (see Figure 3c) showed a flat and glossy surface as well as a gloomy and fibrous surface, an increase in the area of gloomy and fibrous cast iron compared to the raw material and austempered nodular cast iron with a holding time of 30 minutes. Figure 3d shows the fracture surface of austempered nodular cast iron with a holding time of 90 minutes. It can be seen that there are more gloomy and fibrous areas than in other specimens. This indicates that longer austempering holding time will increase the toughness of nodular cast iron [35].

4. Conclusion

From the results and discussions, it can be concluded that the austempering process will make the ferrite phase combine with carbon to form cementite and thus more pearlite. The increase in austempering holding time will cause the ferrite to increase and the pearlite to decrease. As a result, an increase in austempering holding time will result in an increase in the toughness of nodular cast iron.

Acknowledgments

The authors would like to acknowledge Universitas Muhammadiyah Surakarta for research funding number 145.3/A.3-III/LRI/VII/2022. The authors would also like to thank the Material Laboratory of The Mechanical Engineering Department at Universitas Muhammadiyah Surakarta for facilitating the material testing process.

References

[1] Li Z, Peng H, Liu Y, Su X, Kawi S and Wang J 2022 *Journal of Materials Research and Technology* **16** 1402-1412
[2] Collini L, Moroni F and Pirondi A 2019 *Procedia Structural Integrity* **18** 671-687
[3] Li Y, Dong S, Liu X, He P, Ren X, Yan S and Xu B 2021 *Optics & Laser Technology* **135** 106684
[4] Vaško A 2020 *Materials Today: Proceedings* **32(2)** 168-173
[5] Bleicher C, Kaufmann H and Melz T 2021 *International Journal of Fatigue* **147** 106171
[6] Darmawan A S, Purboputro P I, Yulianto A, Anggono A D, Wijianto, Masyrukan, Setiawan R D and Kartika N D 2020 *Materials Science Forum* **991** 17-23
[7] Megahed H, El-Kashif E, Shash A Y and Essam M A 2019 *Journal of Materials Research and Technology* **8(1)** 1188-1196
[8] Alabbasian F, Boutorabi S M A and Kheirandish S 2016 *Materials Science and Engineering: A* **651** 467–73
[9] Lukhi M, Hütter G and Kuna M 2018 *Procedia Structural Integrity* **13** 607-612
[10] Oksanen V, Andersson P, Valtonen K, Holmberg K and Kuokkala V T 2013 *Wear* **308** 199–205
[11] Sommer N and Böhm S 2022 *Journal of Advanced Joining Processes* **5** 100078
[12] Yulianto A, Soenoko R, Suprapto W and Sonief A 2021 *Acta Metallurgica Slovaca* **27(3)** 127–132
[13] Andriollo T, Tiedje N and Hattel J 2020 *Mechanics of Materials* **148** 103414
[14] Hariningsih H, Lutiyatmi L and Daryanto T 2022 *Applied Research and Smart Technology* **3(1)** 31–40
[15] Masyrukan, Darmawan A S, Hariyanto A, Purboputro P I, Ihwanudin H A and Pamungkas M I 2022 *Media Mesin: Majalah Teknik Mesin* **23(2)** 106-113 [in Bahasa]
[16] Sugito B, Anggono A D and Qomarudin A 2020 *International Journal of Emerging Trends in Engineering Research* **8(9)** 5362-5366
[17] Sckudlarek W, Krmasha M N, Al-Rubaie K S, Preti O, Milan J C G and da Costa C E 2021 *Journal of Materials Research and Technology* **12** 2414-2425
[18] Akinribide O J, Akinwamide S O, Obadele B A, Ogundare O D, Ayeleru O O and Olubambi P A 2021 *Materials Today: Proceedings* **38(2)** 1174-1182
[19] Eraslan D, Balcı A, Çetin B, Uçak N, Çiçek A, Yılmaz O D and Davut K 2021 *Journal of Materials Research and Technology* **11** 1443-1456
[20] Silva K H S, Carneiro J R, Coelho R S, Pinto H and Brito P 2019 *Wear* **440–441** 203099
[21] Akinribide O J, Akinwamide S O, Ajibola O O, Obadele B A, Olusunle S O O and Olubambi P A 2019 *Procedia Manufacturing* **30** 167-172

[22] Ghasemi R, Hassan I, Ghorbani A and Dioszegi A 2019 *Materials Science and Engineering: A* **767** 138434
[23] Sarkar T, Bose P K and Sutradhar G 2018 *Materials Today: Proceedings* **5(2) Part 1** 3664-3673
[24] Pereira L, do Amaral R F, Júnior M W and de Barcellos V K 2020 *Journal of Materials Research and Technology* **9(3)** 3055-3063
[25] Kühn F, Brimmers J and Bergs T 2021 *Procedia CIRP* **99** 214-219
[26] Krawiec H, Vignal V, Lelito J, Krystianiak A and Ozga P 2021 *Corrosion Science* **185** 109437
[27] Wang B, Qiu F, Barber G C, Pan Y, Cui W and Wang R 2020 *Journal of Materials Research and Technology* **9(5)** 9838-9855
[28] Wang X, Du Y, Liu B and Jiang B 2021 *Materials Science and Engineering: A* **804** 140513
[29] Soria S R, Li X H, Schulz M, Boin M and Hofmann M 2020 *Materials Characterization* **166** 110453
[30] Lee S, Yu J H, Park S, Shim D and Choi Y 2021 *Journal of Materials Research and Technology* **15** 189-198
[31] Siswanto W A and Darmawan A S 2012 *Research Journal of Applied Sciences, Engineering and Technology* **4(10)** 1277-1286
[32] Li N, Xing S and Bao P 2013 *Journal of Iron and Steel Research, International* **20(6)** 58-62
[33] Mitelea I, Bordeaşu I, Pelle M and Crăciunescu C 2015 *Ultrasonics Sonochemistry* **23** 385-390
[34] Gutie´rrez, I 2013 *Materials Science and Engineering: A* **571** 57-67
[35] Chen X, Zhao L, Zhang W, Mohrbacher H, Wang W, Guo A and Zhai Q 2019 *Materials Science and Engineering: A* **760** 186-194