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EFFECT OF TEMPERATURE AND TIME OF TWO-STEP AUSTEMPERING METHOD ON MECHANICAL PROPERTIES FOR NODULAR CAST IRON

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ABSTRACT

This research attempts to investigate the mechanical properties of nodular cast iron using new heat treatment technique. Novel two-step austempering technique was executed to obtain better mechanical properties for nodular cast iron. The results from this method were then compared to a conventional heat treatment, namely single-step austempering method. Single-step and two-step austempering methods were done at 900 ºC of austenitic temperature for 60 minutes. For two-step austempering method, the second step started at 260 ºC for 10 minutes increased gradually at 280, 310, and 340 ºC for 60 minutes. The mechanical properties of nodular cast iron increased significantly using two-step austempering method compared to the conventional and single-step austempering methods. The highest tensile strength was obtained using two-step austempering method at 340 ºC for 60 minutes followed by 310 ºC and 280 ºC. On the contrary, the toughness of nodular cast iron decreased at 340 ºC.

Keywords: nodular cast iron, single-step austempered, two-step austempered.

INTRODUCTION

Along with the development of Nodular Cast Iron (NCI) in meeting the quality requirement as occurred in the era of 70s, a number of experiments has been conducted, each of which is by adding certain alloying elements to nodular cast iron or by performing a heat treatment. However, this heat treatment process commonly is still conventional that is using single-step austempering method resulting in Austempered Ductile Iron (ADI).

Concerning with the improvement of mechanical properties of Nodular Cast Iron (NCI), Sheikh (2008) conducted a research to investigate the characteristics and mechanical properties of NCI under single-step heat treatment. The research then showed an optimum result towards the mechanical properties obtained at 900 ºC of austenite temperature with the holding time of 60 minutes and at 270 ºC of austempered temperature with the holding time of 90 minutes [1].

Similarly, Bish (2009) conducted a research showing that NCI with and without any chemical element, in this case copper experienced an increase in tensile strength and roughness. The optimal tensile strength and optimum roughness were achieved at 260 ºC of the austempered temperature with the holding time of 60 minutes [2].

Meanwhile, Panda (2011) concluded from the research result that the optimal value of the toughness and tensile strength that had been obtained occurred at 250 ºC of austempered temperature with the holding time of 60 minutes [3].

The following development was at the beginning of 2004 in which a new model of heat treatment called two-step austempering method was developed. The result of the development towards the materials of NCI and ADI showed the increase of tensile strength and yield strength overtime. However, it was found that ductility and toughness decreased. The best crack of roughness was obtained in two-step austempering method (24%) in which it was higher than the conventional single-step heat treatment [4].

Meanwhile, Yang (2005) investigated the mechanical properties of ADI material under the single-step and two-step austempering heat treatment. The result then showed that the toughness and the tensile strength under two-step austempering heat treatment resulted in a higher value compared to ADI under the single-step heat treatment [5].

The critical difference between the previous heat treatment research and this research lies on the austempered temperature and time. The single-step and two-step austempered temperature in the previous research ranged from 250-270 ºC with the holding time of 90 - 120 minutes. In this research, the austempered temperature was performed at the temperature higher than the mentioned temperatures; those are 280, 310, and 340 ºC with the holding time of 60 minutes. In addition, in the ADI material at the initial austempered temperature of 260 ºC was for 60 minutes, followed by the second step with variety of temperatures at 280, 310, and 340 ºC for 60 minutes. Thus, this research will complete the result of previous research information related to the heat treatment both in single-step austempering and in two-step austempering method.

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METHODOLOGY

Before conducting the heat treatment and testing, the cylindrical raw material of Nodular Cast Iron in diameter of 25 mm was partly cut to obtain its sample to test its chemical composition using spectrograph. The figures below are the single-step austempering heat treatment austempering method (Figure 1) and two-step one (Figure-2). The heat treatment was conducted in a furnace manually controlled through the following stages in Figure-1 and Figure-2.

The heat treatment was conducted for line a-b and b-c in the single-step and two-step austempering method at the temperature of 900°C with the holding time of 60 minutes. Furthermore, the line c-d in the single-step was quenched into 50% salt solution of $NaNO_3$ + 50% KNO_3.

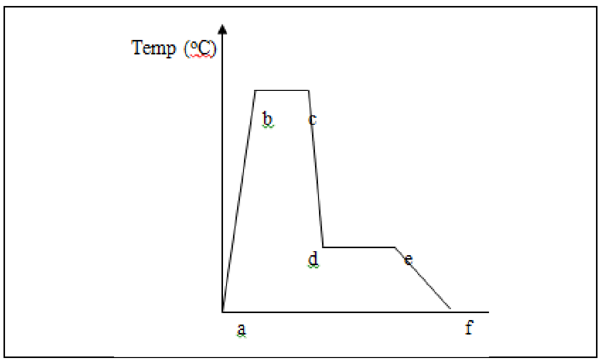

Figure-1. Single-step austempered [8].

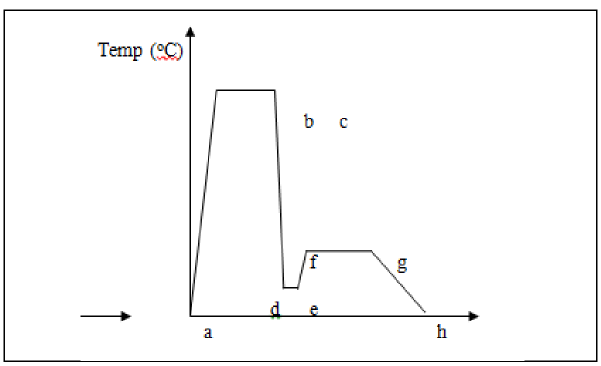

Figure-2. Two-step austempered [9].

The heat treatment was performed in the single-step and two-step austempering method at the temperature of 900 ºC with the holding time of 60 minutes. Subsequently, the line c-d in the single step was quenched in the salt solution of 50% $NaNO_3$ + 50% KNO_3. Then, it was reheated at the austempered temperature at 280 ºC, 310 ºC, and 340 ºC. Meanwhile, in two-step austempering method, after being quenched as occurred in other, it was also reheated. In the first step, the line d-e was given the austempered temperature at 260 ºC with the holding time of 10 minutes. In the second step, the temperature in the austempered line e-f was increased as in the austempered single step into 280 ºC, 310 ºC, and 340 ºC. An equal holding time was given in the line d-e in the single-step austempering method and in the line f-g in two-step one that was for 60 minutes before being quenched outside air (room temperature) of line e-f for single-step austempering method and line g-h for two-step one. After the process of heat treatment in austempered single-step and austempered two-step was completed, it was followed by the next step that was by making the test specimen consisting of tensile testing, impact testing and toughness testing and microstructure testing.

RESULT AND DISCUSSIONS

Figure-3a below presents the result of the tensile testing for Nodular Cast Iron and the result of heat treatment for single-step and two-step austempering methods. Based on the result of the tensile testing, it was found that the tensile strength increased along with the increase of austempered temperature. The highest tensile strength in the single-step method occurred at 340 ºC of the austempered temperature, and in the austempered two-step one, the highest tensile strength occurred at 340 ºC with the holding time of 60 minutes.

Figure-3b shows the relationship between yield strength and temperature and time austempered in the raw material of nodular cast iron, single-step and two-step austempering methods. It was identical with the testing result of the maximum tensile strength that the yield strength showed a linear value with the tensile strength. It indicates that the more increasing tensile strength will lead to the increasing yield strength. The highest yield strength in the single-step austempering method occurred at 340ºC of the austempered temperature, while the highest yield strength of two-step one occurred at 340 ºC of the austempered temperature with the holding time of 60 minutes.

The graph in Figure-3c shows the relationship between elongation and the austempered temperature and time. It can be seen that the elongation was inversed compared to the tensile strength and yield strength. The highest elongation was achieved in the raw material of nodular cast iron and the lowest one occurred in the tensile strength and the optimum yield strength.

It is noticeable that the change of mechanical properties of the tensile strength in the single-step method and two-step austempering one was highly determined by the change of the austempered temperature and time.

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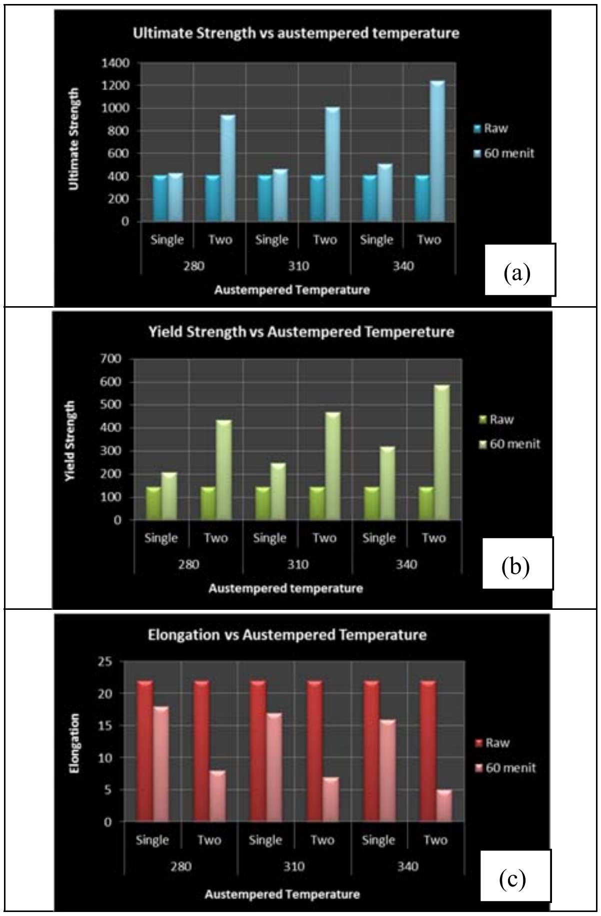

Figure-3. The graph of relationship between the ultimate strength and the austempered temperature (b). The graph of relationship between the yield strength and the austempered temperature (c). The graph of the relationship between elongation and the austempered temperature.

The graph in Figure-3 below presents the relationship between the percentage of ferrite matrix phase and the size of nodular diameter and the distribution of nodular raw material, single-step austempering method and two-step one. The graphs refer to the highest value of mechanical properties occurred at 340 ^{o}C with the holding time of 60 minutes for single-step, and at the temperature of 340 ^{o}C with the holding time of 60 minutes in the two-step austempering process.

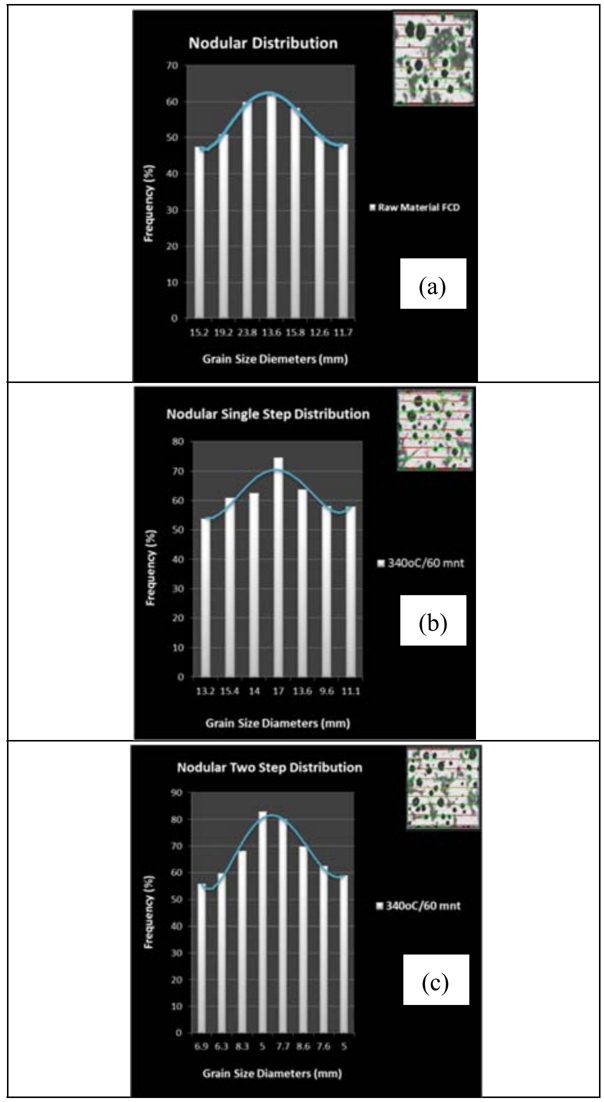

Figure-4. The distribution and the nodular diameter a). Raw material b).Single step 340 ^{o}C/60 minutes c). Two step 340 ^{o}C/60 minutes.

The testing result on the microstructure of raw material of nodular cast iron and the result of the heat treatment of single-step and two-step austempering method (Figure 4a, 4b, and 4c) consisted of the globular graphite and ferrite and pearlistic matrix with the more percentage of ferrite volume fractions of two-step compared to the single-step austempering method. In addition, the total carbon, size and the distribution of carbon in the matrix of two-step austempered was more than both the single step and the raw material. The ferrite matrix was ductile and pearlistic matrix had higher toughness but ductile. However, the decrease of the pearlistic content and the increase of ferrite content in the matrix can influence the decrease of the impact energy.

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CONCLUSIONS

Two-step austempering resulted in a better mechanical property changes compared to the conventional treatment (single-step austempering method). The 340 ºC of austempered temperature with the holding time of 60 minutes in two-step austempering method is recommended as the better temperature and time to result in the tensile strength and the optimum toughness. The 280 ºC of the austempered temperature with the holding time of 60 minutes in two-step austempering method was recommended as the better temperature and time to result in an optimum toughness.

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