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*Original Article*

# Effect of Two-Stage Heat Treatment on Gray Cast Iron GC250

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***Abstract*** *- This study was intended to examine the effect of two-stage heat treatment on gray cast iron GC250. The heat treatment was conducted in two stages using a high-frequency induction furnace. In the first stage, an austenitizing heat treatment was conducted by retaining the material at 920˚C in an Ar atmosphere for 2h and then cooling it with water. In the second stage, austempering heat treatment was conducted by retaining the material at 350˚C in an Ar atmosphere for 2h and then cooling it with water. To determine the physical properties of gray cast iron and alloy iron after two-stage heat treatment, the tensile strength, elongation, and hardness values (HV0.05) were measured 6 and 12 times, respectively; the average value was measured by excluding the maximum and minimum values; and the microstructure was observed through SEM. As a result, the tensile strength was measured to be 336 MPa, the surface hardness HRA 79.97, and the elongation rate 14.89%, indicating that the tensile strength was improved by 43%: the surface hardness was improved by 31%, and the elongation rate was improved by 17%, compared to the initial material GC250. The microstructures were compared through microstructure photographs.*

***Keywords*** *- Gray cast iron, 2-Stage heat-treatment GC250, Surface hardness, Tensile strength, Heat treatment.*

## 1. Introduction

Among the castings produced in the world's major countries, iron-based castings account for about 80% and cast iron accounts for 70% due to their advantages, including low price and high utilization.[7] Among them, gray cast iron was named gray cast iron because the microstructure of the cross section appeared gray. Compared to carbon steel, it contains 2.11~6.7%, a higher carbon content than carbon steel. Since gray cast iron has good machinability, it is possible to make products with complex shapes by melting it.

In addition, it is widely used as a material for the body of mechanical structures due to its low price. However, since it has almost no bending or elongation properties, it cannot be rolled or hammered to make a product and is fragile to impact. Therefore, despite its superior castability, it has slight elongation due to its high brittleness, and its mechanical properties are poor at high temperatures due to its high carbon content [9,10]. Therefore, manufacturing adds various alloying elements such as Ni, Cr, Mo, and gray earth elements to improve the physical properties of grey cast iron.

In this study, the material's physical properties change was observed under microstructure control through two-stage heat treatment for bainite transformation to increase surface hardness, tensile strength, and elongation rate for higher utilization of gray cast iron among cast irons with the highest production among commercial casting products.

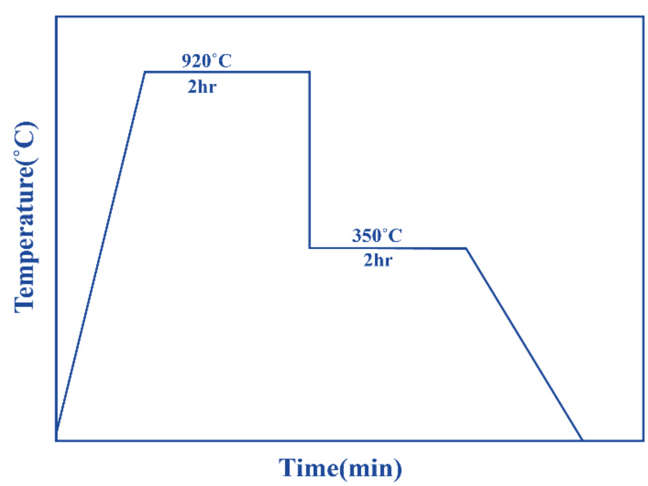


**Fig. 1 Heating cycle of heat treatment**

## 2. Materials and Experiment Method

In this study, gray cast iron GC250 was used, and its chemical composition was confirmed through XRF analysis. In particular, Vickers (HV 0.05) hardness, elongation rate, and strength were measured to observe changes in physical properties before and after heat treatment of gray cast iron GC250. The heat treatment was conducted in two stages using a high-frequency induction furnace. The entire heat-treatment process is presented in Fig.1. In the first stage, normalization was performed by retaining the material at 920˚C in an Ar atmosphere for 2 h and then cooling it with water. In the second stage, austempering heat treatment was conducted by retaining the material at 350˚C in an Ar atmosphere for 2h and then cooling it with water. The raw material was processed into a rod shape for physical property analysis using a high-speed cutter. Then a tensile test, Brinell hardness test, XRF (X-Ray Fluorescence), and C/S (Carbon/Sulfur) analysis were conducted. Tensile strength and elongation rate were measured 6 times in total, and the remaining 4 values were averaged after excluding the maximum and minimum values. The microstructure was prepared by polishing, polishing, and etching the material, and it was observed through a scanning electron microscope (SEM).

## 3. Result and Discussion

### *3.1. Result of Analyzing the Physical Properties of GC250*

The chemical composition of GC250 is presented in the table. 1, it was confirmed that it was cast iron with a carbon content of 3.53%.

**Table 1. Chemical composition of gray cast iron GC250**

| XRF | |
|---|---|
| **Element** | **wt.%** |
| Fe | 92.99 |
| C | 3.53 |
| Si | 2.69 |
| Mn | 0.64 |
| S | 0.08 |
| P | 0.07 |

**Table 2. Results of testing the hardness GC250**

| GC250 | | | | |
|---|---|---|---|---|
| **Times of measurement** | **D1** | **D2** | **Hardness (HV0.05)** | **HRA** |
| **1** | 23.61 | 21.90 | 179.07 | 54.77 |
| **2** | 19.10 | 18.26 | 265.72 | 62.78 |
| **3** | 19.38 | 18.27 | 261.64 | 62.51 |
| **4** | 21.34 | 22.13 | 196.27 | 56.63 |
| **5** | 16.01 | 17.43 | 331.67 | 67.11 |
| **6** | 22.23 | 22.14 | 188.39 | 55.84 |
| **7** | 20.53 | 18.95 | 237.95 | 61.00 |
| **8** | 19.11 | 17.98 | 269.60 | 63.10 |
| **9** | 19.95 | 20.06 | 231.68 | 60.61 |
| **10** | 18.53 | 18.50 | 302.24 | 65.32 |
| **Average** | **19.98** | **19.56** | **246.42** | **60.97** |

**Table 3. Result of testing the tensile strength of GC250**

| Material No. | Tensile strength | Elongation rate |
|---|---|---|
| | **MPa** | **%** |
| **GC250 – 1st time** | 199.195 | 13.24 |
| **GC250 – 2nd time** | 200.498 | 13.65 |
| **GC250 – 3rd time** | 190.091 | 10.88 |
| **GC250 – 4th time** | 190.816 | 11.279 |
| **Average** | **195.15** | **12.26225** |

In addition, the surface hardness and tensile strength values were presented in the table. 2, Table. 3, the Brinell hardness value (HRA) of 60.97 was calculated through the Vickers hardness (HV0.05).

### *3.2. Heat Treatment*

The gray cast iron GC250 was retained at 920˚C for 2 hrs and then water-cooled, the material was further retained at 350˚C for 2 hrs and then water-cooled, and the physical properties were analyzed. The results are presented in the tables 4, 5 and fig. 2, fig. 3.

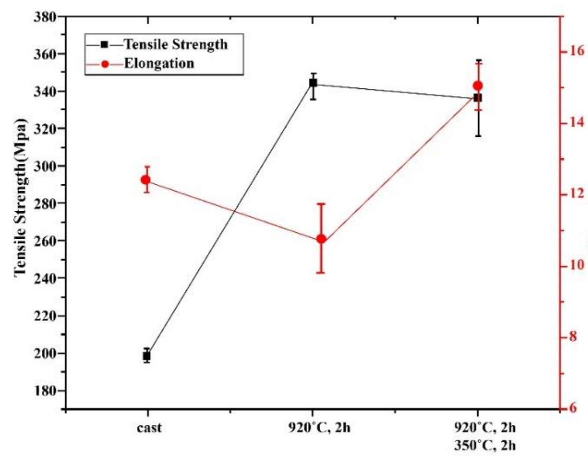


**Fig. 2 Comparison of the tensile test results between initial gray cast iron and heat-treated gray cast iron**

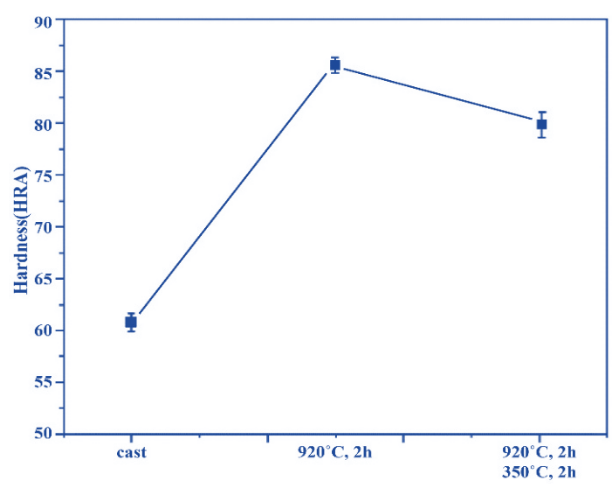


**Fig. 3 Comparison of the hardness test results between initial gray cast iron and heat-treated gray cast iron**

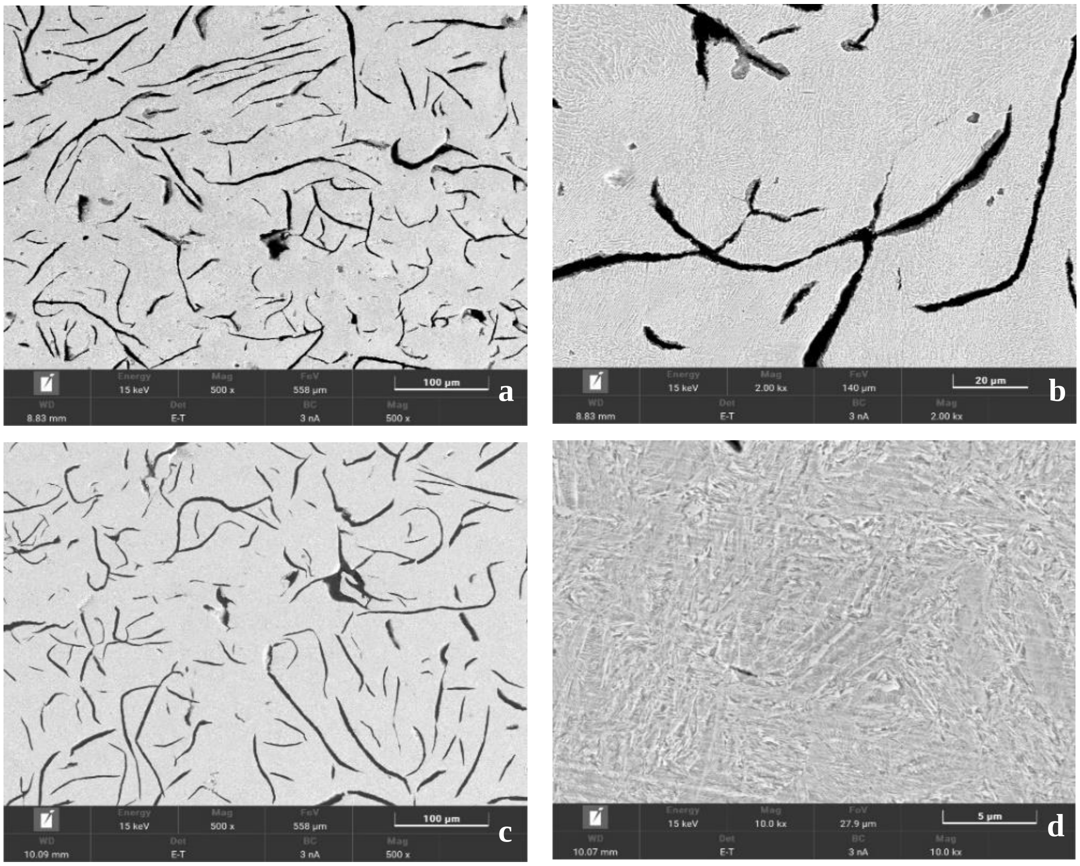


**Fig. 4 a) Microstructure photograph of gray cast iron (X 500), b) Microstructure photograph of gray cast iron (X 2000), c) Microstructure photograph after two-stage heat treatment (X 500), and d) Microstructure photograph after two-stage heat treatment (X 2000)**

In the initial physical properties of gray cast iron GC250, after heat treatment at 920˚C for 2 h, the surface hardness and tensile strength increased by 28.36% and 43.33%, respectively, which confirms that the elongation rate decreased by 12.3%. After heat treatment at 350˚C for 2 hrs, the tensile strength and surface hardness increased by 23.76% and 41.98%, respectively, and the elongation rate increased by 27.76%, compared to the initial gray cast iron GC250.

The microstructure of the initial gray cast iron and that of the gray cast iron treated with heat in two stages were presented in Fig. 4. As a result of microstructure observation, a pearlite matrix and flake graphite were observed in the initial gray cast iron. A structure considered to be a lower bainite structure was observed in the material treated with heat in two stages. It is considered that the remaining austenite was transformed into bainite due to automatization at 920˚C and then au tempering at 350˚C. [4]

**Table 4. Tensile test analysis results after retaining the material at 920˚C for 2hrs and 350˚C for 2hrs**

| Experimental methods and number of sessions | Tensile strength | Elongation rate | Experimental methods and number of sessions | Tensile strength | Elongation rate |
|---|---|---|---|---|---|
| | MPa | % | | MPa | % |
| 920˚C, 2hr-1st session | 325.279 | 9.224 | 920˚C, 2hr<br>350 ˚C, 2hr -1st session | 266.717 | 13.363 |
| 920˚C, 2hr-2nd session | 359.498 | 10.521 | 920˚C, 2hr<br>350 ˚C, 2hr -2nd session | 337.737 | 13.872 |
| 920˚C, 2hr-3rd session | 352.091 | 11.827 | 920˚C, 2hr<br>350 ˚C, 2hr -3rd session | 331.25 | 16.931 |
| 920˚C, 2hr-4th session | 342.816 | 11.476 | 920˚C, 2hr<br>350 ˚C, 2hr -4th session | 409.571 | 15.422 |
| **Average** | **344.921** | **10.762** | **Average** | **336.319** | **14.897** |

**Table 5. Results of analyzing the surface hardness after retaining the material at 920˚C for 2hrs and at 350˚C for 2hrs**

| 920˚C, 2hr | | | | | 920˚C, 2hr - 350˚C 2hr | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Times of measurement** | **D1** | **D2** | **Hardness (HV0.05)** | **Hardness scale (HRA)** | **Times of measurement** | **D1** | **D2** | **Hardness (HV0.05)** | **Hardness scale (HRA)** |
| **1** | 9.28 | 9.84 | 1014.51 | 86.07 | **1** | 11.51 | 11.49 | 701.10 | 81.31 |
| **2** | 9.27 | 10.13 | 985.44 | 85.88 | **2** | 10.96 | 11.22 | 753.89 | 82.45 |
| **3** | 9.55 | 8.87 | 1093.09 | 86.6 | **3** | 11.23 | 11.48 | 719.12 | 81.78 |
| **4** | 9 | 10.38 | 987.47 | 85.9 | **4** | 10.39 | 11.53 | 771.88 | 82.80 |
| **5** | 9.83 | 10.38 | 908.03 | 85.12 | **5** | 13.77 | 12.32 | 544.86 | 76.83 |
| **6** | 9.58 | 9.84 | 983.41 | 85.87 | **6** | 14.05 | 16.05 | 409.36 | 71.34 |
| **7** | 10.11 | 9.84 | 931.85 | 85.48 | **7** | 10.39 | 11.21 | 794.92 | 83.29 |
| **8** | 9.56 | 10.39 | 931.85 | 85.48 | **8** | 12.10 | 12.74 | 601.08 | 78.67 |
| **9** | 11.8 | 13.28 | 589.63 | 78.35 | **9** | 11.80 | 11.76 | 668.16 | 80.53 |
| **10** | 9 | 9.88 | 1040.47 | 86.25 | **10** | 11.27 | 12.19 | 673.87 | 80.70 |
| **Mean** | **9.70** | **10.28** | **946.58** | **85.10** | **Mean** | **11.75** | **12.20** | **663.82** | **79.97** |

## 4. Conclusion

This study examined the effect of two-stage heat treatment on gray cast iron GC250. To improve the mechanical properties of the material, two-stage heat treatment: i.e., heat-treatment at 920˚C for 2hrs, and heat treatment at 350˚C for 2 hrs, was conducted, and the change in alloy properties and microstructure was observed. As a result of the experiment, austenitenizing proceeded through heat treatment at 920 ˚C for 2 hrs. in the phase where flake graphite was deposited in the existing pearlite matrix, and the bainite transformation of bainite lath into coarse feathery bainite proceeded through austempering heat treatment at 350 ˚C for 2 hr. Therefore, as the microstructure was transformed into bainite after heat treatment in the initial GC250 where flake graphite was precipitated in the pearlite matrix, the tensile strength increased by 43%, the surface hardness by 31%, and the elongation rate by 17% compared to the gray cast iron GC250.

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