Study on the Influence of Nano-SiC on the Structure and Properties of Nodular Cast Iron

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Abstract. In this paper, the effect of adding Nano-SiC on the structure and mechanical properties of nodular cast iron during inoculation and spheroidizing process is mainly studied. Three sets of samples were set up: one group is without adding Nano-SiC, and the other two groups are adding Nano-SiC in the spheroidizing process and inoculation step. The three groups of castings were sampled from the core and 1/4 respectively and treated by isothermal quenching. The influences of Nano-SiC and heat treatment process on the microstructure and mechanical properties of nodular cast iron were discussed through the observation of impact work, hardness and metallographic structure of Vivtorinox. The experimental results show that with the addition of Nano-SiC, the spheroidization rate, spheroidization degree and graphitization of the graphite in casting structure are improved. In mechanical properties, the impact toughness of the samples with adding Nano-SiC during inoculation is the best, and the hardness of nodular cast iron can be improved. After heat treatment, the impact toughness of nodular cast iron samples increased obviously, but the hardness decreased generally.

1. Introduction

Nano-SiC powder has excellent properties such as high hardness, good creep resistance, chemical resistance, good oxidation resistance, small thermal expansion coefficient and high thermal conductivity. In this paper, the microstructure, hardness and impact toughness of nodular cast iron which with adding Nano-SiC were studied, so as to improve the comprehensive mechanical properties of nodular cast iron.

2. Test and Treatment of Nodular Cast Iron

2.1. Material Preparation

There were total six casting spheres which divided into three groups, the first was a cast sphere without adding Nano-SiC, the second was the casting sphere which adds Nano-SiC in the inoculation process, the third was the casting sphere which adds Nano-SiC in the spheroidizing process. The feeding method was feeding wire, at the same time casting sphere of each group was divided into two types of Ф150 and Ф100. The casting preparation results are shown in figure 1.
Figure 1. Results of casting preparation

2.2. Wire Cutting Sample Preparation
Before testing, the castings obtained were cut into 10 * 10 * 55mm samples. According to the differences and characteristics of the casting. On three groups of nodular cast iron, respectively preparing samples from core and 1/4 cutting, 2 samples were taken at each place, there were a total of 24 samples. After sampling, all samples were grouped, as shown in table 1.

Table 1. Grouping of samples

| Without nano SiC | Add Nano-SiC in the process of spheroidization | Add Nano-SiC in the process of inoculant |
|------------------|-----------------------------------------------|----------------------------------------|
| 一,φ100 1/4      | 二,φ100 1/4                                   | 三,φ100 1/4                            |
| 一,φ100 core     | 二,φ100 core                                   | 三,φ100 core                           |
| 一,φ150 1/4      | 二,φ150 1/4                                   | 三,φ150 1/4                            |
| 一,φ150 core     | 二,φ150 core                                   | 三,φ150 core                           |

2.3. Heat Treatment Process
The heat treatment process in this study was treated by austempering. First, the samples was heated to 890 ~910°C and kept for 2 hours, let primary matrix structure be completely austenitizing, and then cooled in oil of 80 ~90°C to achieve quenching. Placed the oil quenched castings in a furnace of 240 degrees and kept warm for 3 hours, finally, taken out the samples and cooled it to room temperature. The grouping of samples for heat treatment as shown in table 2.
Table 2. Grouping of samples for heat treatment

| Number | Sample | Number | Sample | (heat) |
|--------|--------|--------|--------|--------|
| 1      | ,φ100 1/4 | 13     | ,φ100 1/4 | heat |
| 2      | ,φ100 core | 14     | ,φ100 core | heat |
| 3      | ,φ150 1/4 | 15     | ,φ150 1/4 | heat |
| 4      | ,φ150 core | 16     | ,φ150 core | heat |
| 5      | ,φ100 1/4 | 17     | ,φ100 1/4 | heat |
| 6      | ,φ100 core | 18     | ,φ100 core | heat |
| 7      | ,φ150 1/4 | 19     | ,φ150 1/4 | heat |
| 8      | ,φ150 core | 20     | ,φ150 core | heat |
| 9      | ,φ100 1/4 | 21     | ,φ100 1/4 | heat |
| 10     | ,φ100 core | 22     | ,φ100 core | heat |
| 11     | ,φ150 1/4 | 23     | ,φ150 1/4 | heat |
| 12     | ,φ150 core | 24     | ,φ150 core | heat |

3. Test data analysis and discussion of nodular cast iron

3.1. Results and Analysis of Impact Test
The data of impact energy measurement are shown in table 3 and figure 2.

Table 3. Impact work of sample

| Number | Type  | Impact energy | Number | Type  | Impact energy |
|--------|-------|---------------|--------|-------|---------------|
| 1      | ,φ100 1/4 | 10.8          | 13     | ,φ100 1/4 | heat | 19.2  |
| 2      | ,φ100 core | 4.8           | 14     | ,φ100 core | heat | 8.3   |
| 3      | ,φ150 1/4 | 3.2           | 15     | ,φ150 1/4 | heat | 6.2   |
| 4      | ,φ150 core | 2.1           | 16     | ,φ150 core | heat | 2.9   |
| 5      | ,φ100 1/4 | 11.6          | 17     | ,φ100 1/4 | heat | 20.5  |
| 6      | ,φ100 core | 13            | 18     | ,φ100 core | heat | 22.7  |
| 7      | ,φ150 1/4 | 3.4           | 19     | ,φ150 1/4 | heat | 7.9   |
| 8      | ,φ150 core | 4.8           | 20     | ,φ150 core | heat | 13.8  |
| 9      | ,φ100 1/4 | 4.1           | 21     | ,φ100 1/4 | heat | 7.8   |
| 10     | ,φ100 core | 3.7           | 22     | ,φ100 core | heat | 6.6   |
| 11     | ,φ150 1/4 | 2.9           | 23     | ,φ150 1/4 | heat | 5.1   |
| 12     | ,φ150 core | 3.5           | 24     | ,φ150 core | heat | 11.3  |
Figure 2. Impact work of sample

Blue represents the samples before heat treatment and red represents the samples after heat treatment. The following conclusions can be drawn from the chart:

1. The impact toughness of nodular cast iron has been improved obviously after heat treatment, and the impact work of all samples is generally improved by 3~9J.
2. The samples which without Nano-SiC and added Nano-SiC during inoculation process have higher impact toughness, but the samples that added Nano-SiC during spheroidizing process have the worst impact toughness.
3. The impact toughness of casting is the most remarkable while adding Nano-SiC in inoculation process. And the impact toughness of the core has been improved, which is higher than the external impact toughness.

3.2. Hardness Test Results and Analysis

Measurements of microhardness are shown in table 4 and figure 3.

| Number | Type       | Hardness (HV) | Number | Type       | Hardness (HV) |
|--------|------------|---------------|--------|------------|---------------|
| 1      | ₁₋₄,φ100 1/4 | 340.58        | 13     | ₁₋₄,φ100 1/4 heat | 256.96        |
| 2      | ₁₋₄,φ100 core | 313.58        | 14     | ₁₋₄,φ100 core heat | 255.06        |
| 3      | ₁₋₄,φ150 1/4 | 324.56        | 15     | ₁₋₄,φ150 1/4 heat | 268.32        |
| 4      | ₁₋₄,φ150 core | 278.68        | 16     | ₁₋₄,φ150 core heat | 248.76        |
| 5      | ₂₋₄,φ100 1/4 | 319.44        | 17     | ₂₋₄,φ100 1/4 heat | 237.72        |
| 6      | ₂₋₄,φ100 core | 348.38        | 18     | ₂₋₄,φ100 core heat | 238.78        |
| 7      | ₂₋₄,φ150 1/4 | 359.72        | 19     | ₂₋₄,φ150 1/4 heat | 255.92        |
Figure 3. Histogram of measurement data of microhardness

Blue represents the samples before heat treatment and red represents the samples after heat treatment. The following conclusions can be drawn from the chart:

1. From the experimental data, it can be seen that after low temperature tempering the hardness of the sample compared to the cast iron samples without heat treatment had a generally declined. The hardness of the cast iron samples which added with Nano-SiC in the inoculation and spheroidizing process, decreased more obviously.

2. Before the heat treatment, the hardness of the cast iron samples which added with Nano-SiC in the inoculation and spheroidizing process compared with the samples without Nano-SiC, the hardness increased significantly.

4. Metallographic Observation and Analysis

4.1. As Cast Microstructure Analysis

4.1.1 Graphite Morphology. Figures 4 and 5 show the graphite morphology of samples 1# and 5#. By observing, it is known that the size of the graphite ball in the 1# sample is larger and the distribution is rather disordered, the graphite spheres in the 5# sample are smaller and more evenly distributed. In contrast to "GBT 9441-2009 ductile iron metallographic examination", the size of graphite is above grade 5, and the spheroidization level is above 3, which meets the requirements of the experiment. When the nano SiC is added, the graphite spheres in the sample are more rounded, and the
splitting effect on the matrix is small under the impact force, which is beneficial to the improvement of the impact toughness of the casting.

**Figure 4.** 1# graphite morphology  
**Figure 5.** 5# graphite morphology

4.1.2 Matrix Structure. After grinding, polishing, etching, rinsing and drying the above 2 kinds of cast samples, the microstructures observed under the microscope are shown in figures 6 and 7.

**Figure 6.** 1# microstructure of as cast  
**Figure 7.** 5# microstructure of as cast

Because the spheroidizing agent can form graphite spheres, it leads to poor carbon content around the graphite and promotes the formation of ferrite. As shown in Figure 3.3 and 3.4, the round black is the graphite ball, and the bright area around is ferrite, in which the large black ones are mainly pearlite, a small amount of free cementite and phosphorus eutectic. According to the metallographic examination standard GB/T9441-2009 of spheroidal graphite, the metallographic analysis of two kinds of samples was carried out. After adding Nano-SiC, the content of ferrite in the as cast structure was increased, and the pearlite decreased. This is mainly because the Nano-SiC can promote the formation of ferrite and reduce the pearlite. At the same time, the content of carbide in the as cast microstructure decreases correspondingly, which is beneficial to the improvement of the impact toughness of the casting.

4.2. Observation and Analysis of Microstructure in Heat Treated State  
In order to study the influence of Nano-SiC on the microstructure of austempered ductile iron, the microstructure of 13# and 17# samples was observed, as shown in figures 8 and 9.
Figure 8. 13# micrograph

Figure 8 shows the microscopic morphology of the 13#, it can be found some feathery upper bainite in the metallographic structure, the distribution of ferrite sheets in the upper bainite is relatively fine. The white bright area of retained austenite is relatively concentrated in the sample. The impact absorption work of the sample is low, this is due to the fact that cementite is distributed between the ferrite sheets in the upper bainite, which is unfavorable to the impact toughness.

Figure 9. 17# micrograph

Figure 9 shows the microscopic morphology of the 17# sample, the resulting lower bainite is acicular, this is because the Nano-SiC can improve the hardenability of ductile iron, the lower bainite can be formed by adding Nano-SiC to the same heat treatment process, these acicular lower bainite are uniformly distributed in the matrix, the carbon in the lower bainite is supersaturated, and have higher dislocation density, so the dispersion of cementite in the matrix is evenly distributed, and the impact toughness is better.

When Nano-SiC was added to the inoculation process, the hardness of the samples is decreased more obviously, Because martensite is produced at 240 degrees of temperature, most austenite in the matrix is metastable austenite, and unstable austenite exists locally in the matrix. This part of austenite will change into martensite in austempering stage. At higher isothermal quenching temperature, carbon atoms can obtain more energy, the diffusion coefficient increases, and the diffusion to austenite is relatively more. In the process of martensite transformation, the total carbon content is retained, and the carbon content in the martensite is gradually decreased as the austempering temperature continues to decrease. The solid solution of carbon in martensite directly affects the hardness of martensite, eventually, make the hardness of ductile iron decreased.

5. Conclusion

1. The hardness of nodular cast iron generally decreases after heat treatment; The hardness of the cast iron samples which added Nano-SiC decreased more obviously after heat treatment; Before the heat treatment, the hardness of the cast iron samples which added Nano-SiC was significantly higher than samples that without adding Nano-SiC.

2. The impact toughness of nodular cast iron samples is obviously improved after heat treatment; When Nano-SiC was added to the spheroidizing process, the impact toughness of the samples was the worst; Samples without Nano-SiC had higher impact toughness. While adding nano SiC in the process of inoculation, the samples has the best impact toughness;

3. Nano-SiC can promote the formation of ferrite, reduce pearlite and the content of carbide in the cast structure which is beneficial to improve the impact toughness of casting.

6. References

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