

## 3%C-18%Cr-1%Mo-2%Ni-1%Mn 고크롬백주철의 탄화물 및 기지조직에 미치는 불안정화열처리의 영향

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## The Effect of Destabilization Heat Treatment on the Carbide and Matrix Microstructures of 3%C-18%Cr-1%Mo-2%Ni-1%Mn High Chromium Cast Iron

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**Abstract** 3%C-18%Cr-1%Mo-2%Ni-1%Mn high chromium cast iron was casted and destabilized at temperatures of 900, 1000 and 1100°C for 1, 2, 4 and 8hr under N<sub>2</sub> atmosphere to observe the effect of destabilization temperature and time on the carbide and matrix structures. In as-cast condition, the microstructure consisted of M<sub>7</sub>C<sub>3</sub> carbides and matrix structures which were composed of 91.50% austenite and 8.50% martensite. Numerous fine secondary carbides were observed in the specimens destabilized at 900°C for 1, 2, 4 and 8hr. But, the number of secondary carbides were much reduced with the increased destabilization temperature. More austenite was formed in the matrix with the higher destabilization temperature. The amounts of austenite in the matrix were 4.23% at 900°C, 29.68% at 1000°C and 66.51% at 1100°C, respectively. However, the effect of destabilization time on the secondary carbide and matrix was very weak compared with that of destabilization temperature. The ranges of the amount of austenite in the matrix from 1hr to 8hr destabilization heat treatment were: 3.95%-4.35% at 900°C, 28.89%-30.15% at 1000°C and 65.13%-67.12% at 1100°C, respectively. The variation ranges were very narrow. The equilibrium concentration of C and Cr in austenite was already reached within 1hr during destabilization heat treatment. After an attainment of the equilibrium concentration of C and Cr in austenite, no more secondary carbide was precipitated from the matrix.

**Key words** high chromium cast iron, destabilization heat treatment, secondary carbides, austenite, martensite

### 1. Introduction

High chromium cast irons have excellent resistance to abrasion, corrosion and oxidation because their microstructures consist of chromium-rich primary and eutectic matrix, and eutectic chromium carbides.<sup>1-10)</sup> However, a large amount of austenite is retained in the as-cast condition whereby inferior properties are resulted. Therefore, the control of matrix microstructure is important for the performance as a wear resistance material. Particularly, the amount of austenite in the matrix should be controlled to provide an optimum performance for industrial applications.

In this research, 3%C-18%Cr-1%Mo-2%Ni-1%Mn high chromium cast iron was casted and destabilized at temperatures of 900, 1000 and 1100°C for 1, 2, 4 and 8 hr under N<sub>2</sub> atmosphere to observe the effect of destabilization temperature and time on the carbide and matrix structures.

### 2. Experimental Procedure

#### 2.1. Preparation of Test Specimen

Specimens were produced using a 15 kg-capacity high frequency induction furnace. The melt was heated upto 1600°C and transferred into a pre-heated teapot pouring ladle. After removal of any dross and slag, the melt was poured at 1500°C into the pep-set mold in which two sets of 20 mmØ×165 mmL cylindrical bars were designed.

#### 2.2. Destabilization Heat Treatment

The size of specimens used for the destabilization heat treatment was 20 mmØ×10 mmH. These specimens were destabilized at temperatures of 900, 1000 and 1100°C for 1, 2, 4 and 8 hr under N<sub>2</sub> atmosphere, and subsequently air cooled to room temperature.

#### 2.3. X-Ray Diffraction Method

The amount of austenite in the matrix was measured by using a X-ray diffraction method. The areas under the peaks

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of  $g(220)$  and  $g(311)$  were measured for the calculation of the amount of austenite, and those of  $a(200)$  and  $a(220)$  were measured for the amount of martensite.

#### 2.4. Metallographic Examination

The specimens were polished, etched and examined metallographically. The etching solutions used were Villela's etchant (1 g of picric acid, 5 ml of hydrochloric acid and 100 ml of methyl alcohol) and Murakami's etchant (10 g of potassium ferricyanide, 10 g of potassium hydroxides and 100 ml of distilled water).

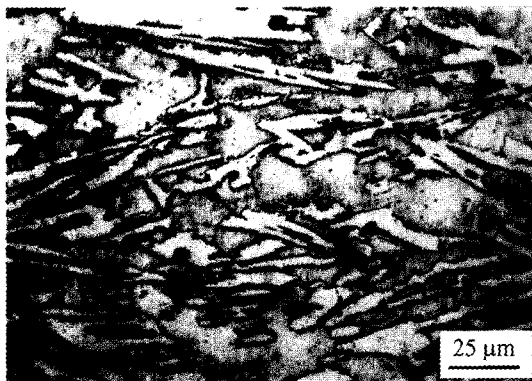
### 3. Results and Discussion

#### 3.1. Microstructures in As-Cast Condition

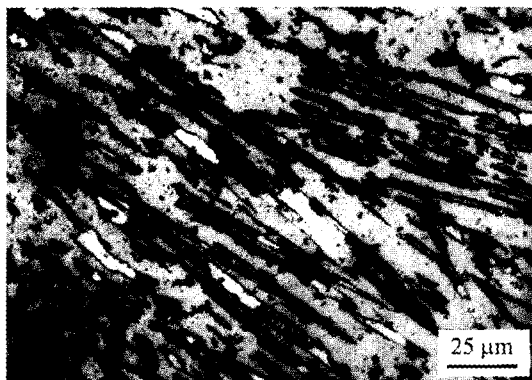
As-cast microstructures of 3%C-18%Cr-1%Mo-2%Ni-1%Mn high chromium cast iron are shown in Fig. 1.

According to the liquidus surface diagram of Fe-C-Cr ternary system, the solidification of 3%C-18%Cr high chromium cast iron starts with the precipitation of austenite as primary phase and followed by the eutectic reaction of (austenite +  $M_7C_3$  carbides).<sup>11)</sup> The final matrix structure is dependent upon the cooling rate after eutectic solidification.

From Fig. 1(a), it can be known that the microstructure



(a) Etched by villela's etchant



(b) Etched by murakami's etchant

**Fig. 1.** As-cast microstructures of 3%C-18%Cr-1%Mo-2%Ni-1%Mn high chromium cast iron.

consists of  $M_7C_3$  carbides and matrix structures which are composed of austenite and martensite. While Villela's etchant etches the carbide and matrix structures in high chromium cast iron, Murakami's etchant only has an ability to etch the carbide structure. In the previous study,<sup>12)</sup> a matrix structure in the as-cast condition was composed of 60% austenite and 40% pearlite when 3%C-18%Cr high chromium cast iron was solidified. But, no pearlite was observed in this study with the addition of 1%Mo, 2%Ni and 1%Mn. It is reported that Mo, Ni and Mn alloying elements have an effect to move the nose of CCT curve toward longer time and lower temperature.<sup>13)</sup> Therefore, it can be postulated that on the cooling of 3%C-18%Cr-1%Mo-2%Ni-1%Mn high chromium cast iron after solidification, the cooling curve did not pass through the pearlite transformation region. It is also known that Ni and Mn alloying elements decrease  $M_s$  temperature greatly. During solidification, most of Ni is distributed in austenite and Mn also has a high distribution coefficient to austenite by which most of austenite in the matrix was stabilized in stead of being transformed into martensite. However, Mo is distributed more to carbides than austenite and sometimes contributes to form  $M_2C$  carbides. But, as shown in Fig. 1(b),  $M_2C$  carbides were not precipitated because of the addition of small amounts of Mo.

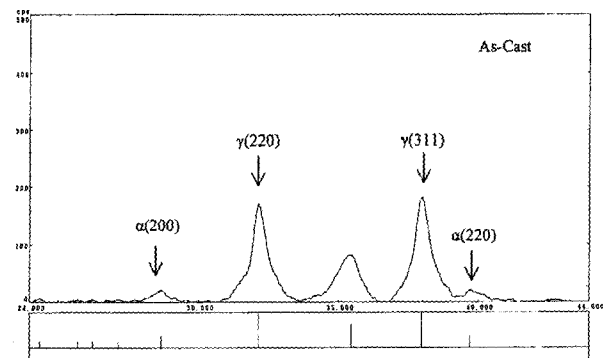
The amounts of austenite and martensite in the matrix were measured with X-ray diffraction pattern, as shown in Fig. 2.

The areas under the peaks of  $g(220)$  and  $g(311)$  are much larger than those of  $a(200)$  and  $a(220)$ , which means the matrix structure is almost composed of austenite. From the calculation of the areas under the peaks, the matrix was consisted of 91.50% austenite and 8.50% martensite.

#### 3.2. Microstructures in Destabilized Condition

Microstructures destabilized at 900, 1000 and 1100°C are shown in Fig. 3, 4 and 5, respectively.

When Fig. 3 is compared with Fig. 1(a), numerous fine secondary carbides are observed in the specimens destabilized



**Fig. 2.** X-ray diffraction pattern of as-cast specimen.

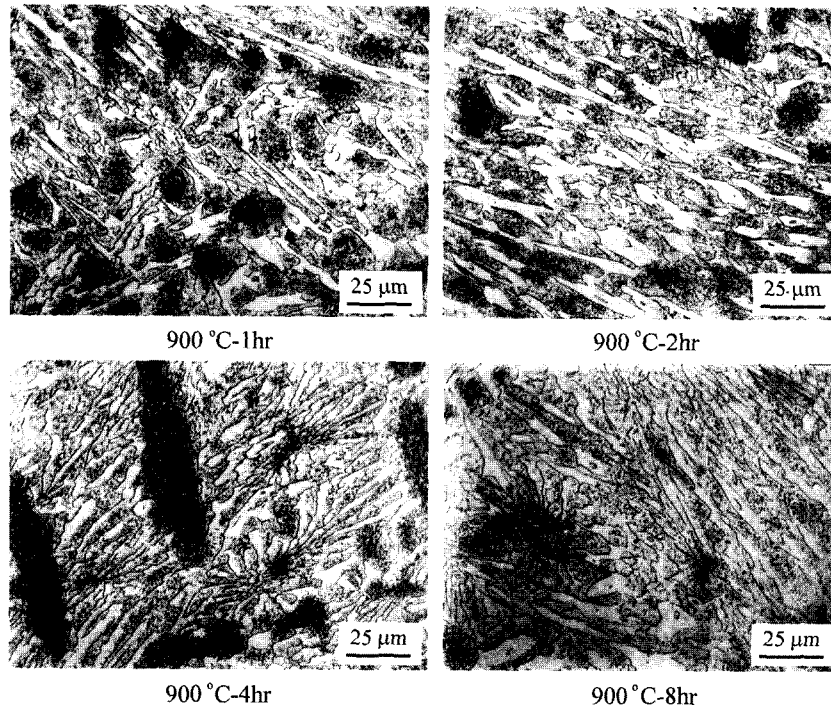


Fig. 3. Microstructures destabilized at 900°C for 1, 2, 4 and 8 hr. (Etched by Vilella's reagent)

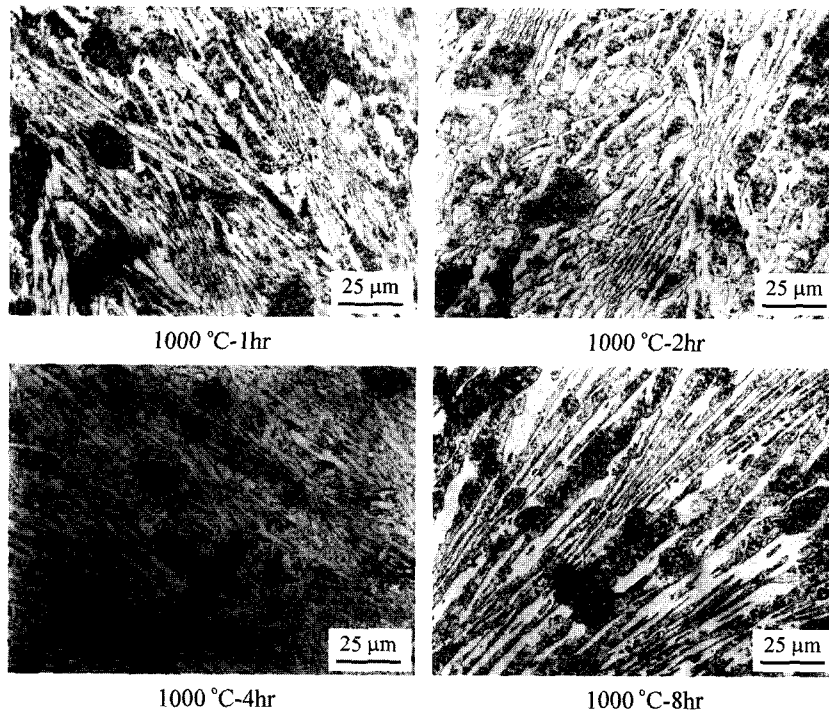


Fig. 4. Microstructures destabilized at 1000°C for 1, 2, 4 and 8 hr. (Etched by Vilella's reagent)

at 900°C for 1, 2, 4 and 8 hr. Because of the faster cooling rate after primary and eutectic solidification encountered in the as-cast specimens, the precipitation of secondary carbides is suppressed and austenite in the matrix is supersaturated with C and Cr whereby Ms temperature is lowered and the amount of austenite in the matrix is increased. When the as-cast specimens are destabilized at 900°C for more than

1 hr, the dissolved C and Cr in austenite are diffused and precipitated as secondary carbides. The effect of destabilization temperature on the precipitation of secondary carbides is also shown in Fig. 3, 4 and 5. Numerous fine secondary carbides are observed in the specimens destabilized at 900°C for 1, 2, 4 and 8 hr. Less but coarse secondary carbides are seen in the specimens held at 1000°C for 1, 2, 4 and

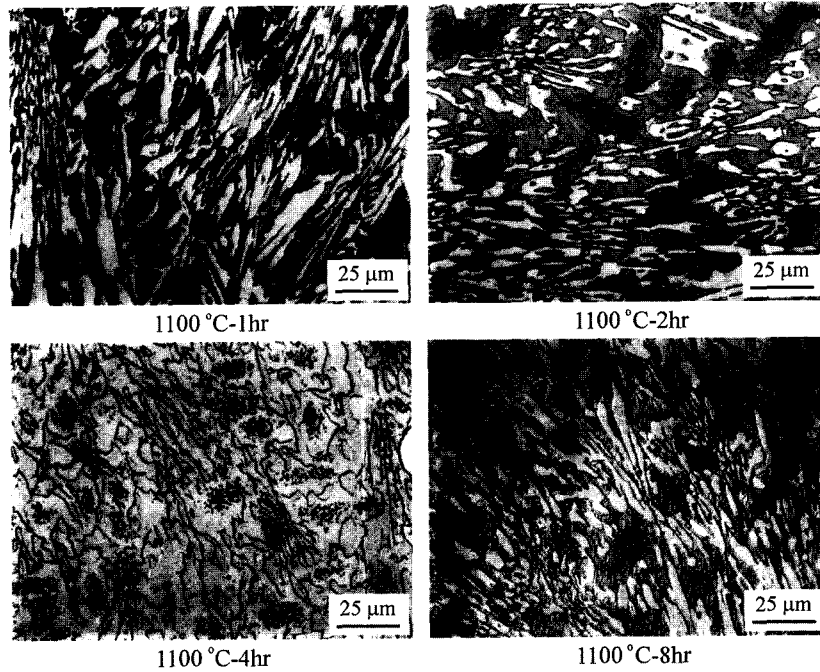


Fig. 5. Microstructures destabilized at 1100°C for 1, 2, 4 and 8 hr. (Etched by Vilella's reagent)

8 hr. However, the number of secondary carbides are much reduced when the specimens are destabilized at 1100°C for 1, 2, 4 and 8 hr. The equilibrium concentration of C and Cr in austenite is determined by Cr/C ratio and destabilization temperature.<sup>14)</sup> At the constant Cr/C ratio(6.0 in this study), the equilibrium concentration of C in austenite is reported to decrease with the decreased destabilization temperature by which more secondary carbides are precipitated and higher Ms temperature is obtained. Therefore, more austenite is formed in the matrix with the higher destabilization temperature. The effect of destabilization temperature on the matrix structure is more evident in the X-ray diffraction patterns shown in Fig. 6, 7, 8 and 9.

As shown in Fig. 6, the areas under the peaks of  $g(220)$  and  $g(311)$  are largest in the specimen destabilized at 1100°C for 1hr and smallest in the specimen destabilized at 900°C for 1 hr. The amounts of austenite in the matrix are 4.23% at 900°C, 29.68% at 1000°C and 66.51% at 1100°C, respectively. As shown in Fig. 7, 8 and 9, a similar trend is also observed in the specimens destabilized for 2, 4 and 8 hr.

However, the effect of destabilization time on the secondary carbide and matrix structure is very weak compared with that of destabilization temperature. As shown in the four specimens destabilized at 900°C in Fig. 3, the variation of the amount of secondary carbide with the increased destabilization time is very slight. The same phenomena are also observed in the specimens destabilized at 1000°C and 1100°C, as shown in Fig. 4 and 5. Therefore, it can be postulated that the equilibrium concentration of C and Cr in austenite is already reached within 1 hr during destabiliza-

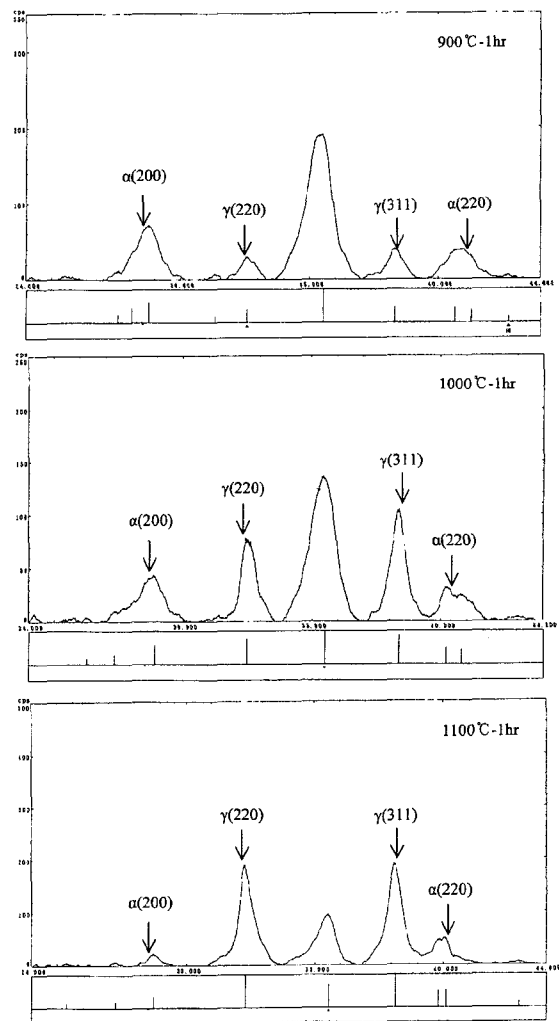


Fig. 6. X-ray diffraction patterns of the specimens destabilized at 900, 1000 and 1100°C for 1 hr.

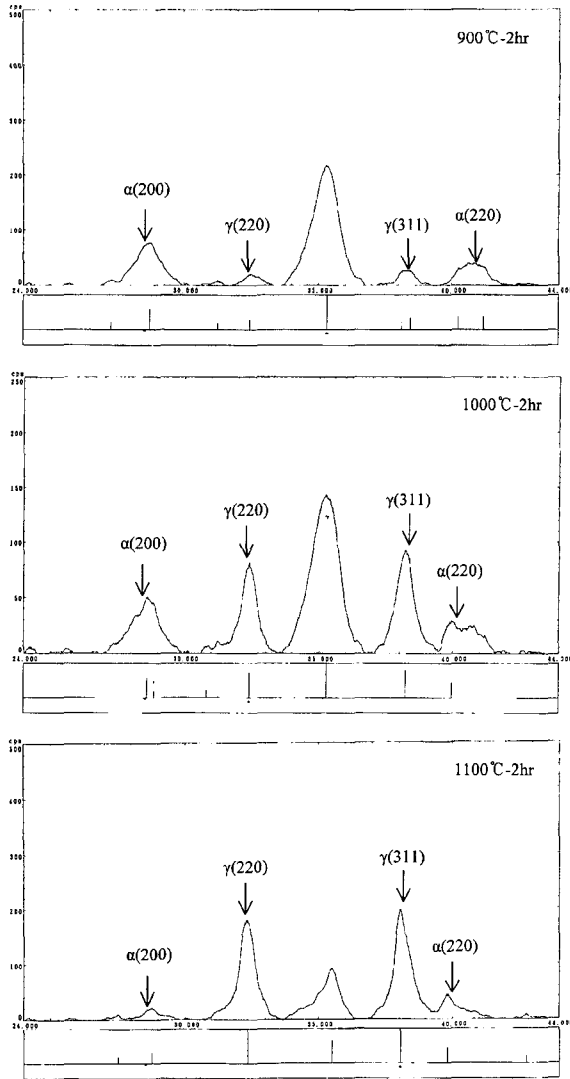


Fig. 7. X-ray diffraction patterns of the specimens destabilized at 900, 1000 and 1100°C for 2 hr.

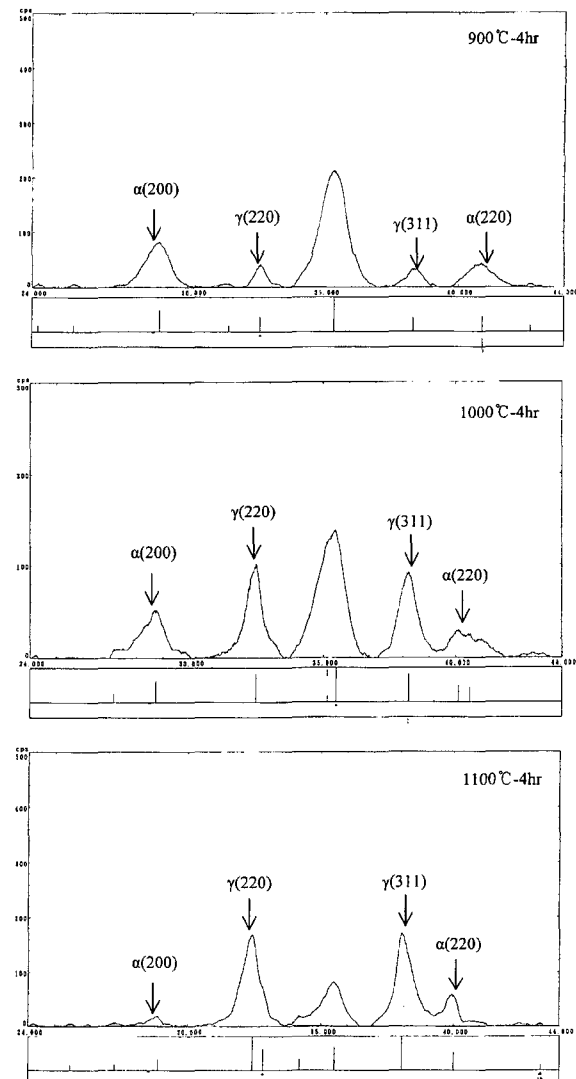


Fig. 8. X-ray diffraction patterns of the specimens destabilized at 900, 1000 and 1100°C for 4 hr.

tion treatment. After an attainment of the equilibrium concentration of C and Cr in austenite, no further more secondary carbide is precipitated from the matrix. It is also evident from the X-ray diffraction patterns, as shown in Fig. 6, 7, 8 and 9. The ranges of the amount of austenite in the matrix from 1 to 8 hr destabilization treatment are: 3.95%-4.35% at 900°C, 28.89%-30.15% at 1000°C and 65.13%-67.12% at 1100°C, respectively. The variation range is very narrow. Therefore, it is useless to continue the destabilization treatment after an attainment of the equilibrium concentration of C and Cr in austenite.

#### 4. Conclusion

In 3%C-18%Cr-1%Mo-2%Ni-1%Mn high chromium cast iron, destabilization heat treatment was conducted at three different temperatures(900, 1000, 1100°C) for four different holding times(1, 2, 4, 8 hr) to observe its effect on

the carbide and matrix structures, and the following conclusions were obtained:

- 1) In as-cast condition, the microstructure consisted of  $M_7C_3$  carbides and matrix structures which were composed of 91.50% austenite and 8.50% martensite.
- 2) Numerous fine secondary carbides were observed in the specimens destabilized at 900°C for 1, 2, 4 and 8 hr. Less but coarse secondary carbides were seen in the specimens held at 1000°C for 1, 2, 4 and 8 hr. However, the number of secondary carbides were much reduced when the specimens were destabilized at 1100°C for 1, 2, 4 and 8 hr.
- 3) More austenite was formed in the matrix with the higher destabilization temperature. The amounts of austenite in the matrix were 4.23% at 900°C, 29.68% at 1000°C and 66.51% at 1100°C, respectively.
- 4) The effect of destabilization time on the secondary carbide and matrix structure was very weak compared with that of destabilization temperature. The ranges of the amount

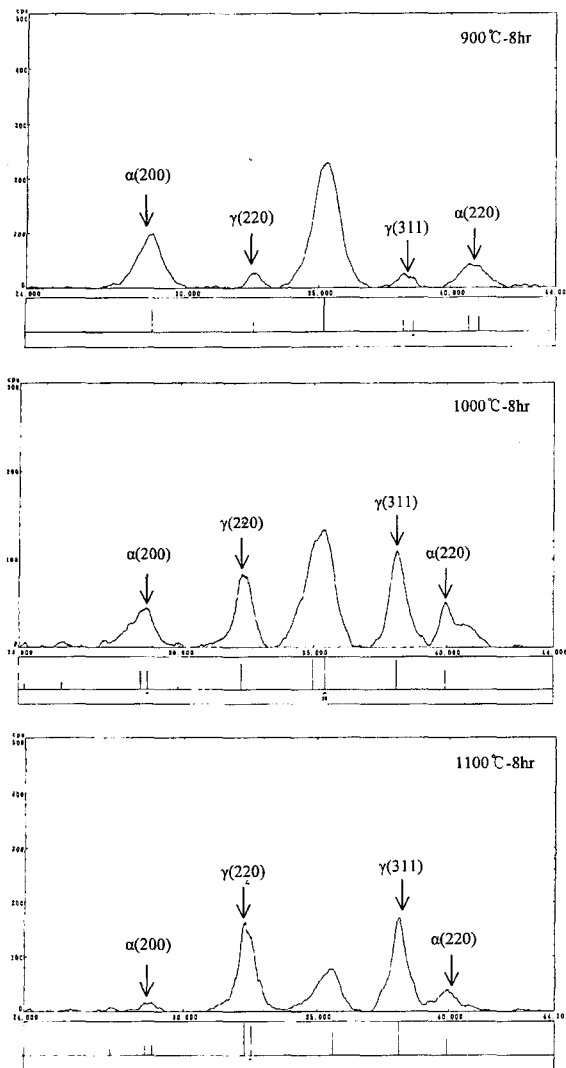


Fig. 9. X-ray diffraction patterns of the specimens destabilized at 900, 1000 and 1100°C for 8 hr.

of austenite in the matrix from 1 to 8 hr destabilization heat treatment were: 3.95%-4.35% at 900°C, 28.89%- 30.15% at 1000°C and 65.13%-67.12% at 1100°C, respectively. The variation range was very narrow.

5) The equilibrium concentration of C and Cr in austenite was already reached within 1hr during destabilization treatment. After an attainment of the equilibrium concentration of C and Cr in austenite, no further more secondary carbide was precipitated from the matrix.

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