A Comparative Study on the Carbon Diffusion Characteristics in C 0.20 - Cr 1.14 Carburized Alloy Steel

Chang-Yeol Oh, Bo-An Kang, Choon Yoo, Sang-Jin Yoon

Abstract*: Gas carburization, which is heat treated with CO_2 gas, is a common heat treatment method used for mass production. This method is used to improve the mechanical properties of most metal products, such as mechanical parts, automotive parts, and aircraft. The experiment was carried out in an RX gas atmosphere containing propane gas in an alloy steel containing C 0.2 wt% And Cr 1.14 wt%. As a result, the Vickers hardness was measured at 725 HV at a carburizing depth of 0.1 mm and 570 HV at 1.5 mm. Observation of the carburized specimens by optical microscope revealed that ferrite and pearlite structures were observed in the pre-carburized structure, but most layered martensite structure appeared after carburization. Simulation results show that the carburizing capacity of the surface layer was up to 0.7% C when the carbon potential was 1.0-1.1 wt% and the diffusion carbon potential was 0.75 wt%. However, when the carbon potential was 1.0 wt% and the diffusion carbon potential was 0.85 wt%, the surface layer was carburized to 0.8 % C. In the future, we will study corrosion resistance and abrasion resistance among the mechanical properties that are necessary to be used as automotive parts in order to contribute to the prolongation of the life span of automobile parts.

***Index Terms*: Gas carburization, Carburizing depth, Carbon diffusion, Simulation**

I. INTRODUCTION

Recent trends in heat treatment related technology are evolving around the automotive sector. According to the Korea Institute of Industrial Technology (2012), the heat treatment rate in the automotive sector is 54%. [1]. In order to transfer the driving force in the automobile field, various parts are assembled in a complicated manner. Therefore, automobile parts should have mechanical properties such as hardness, abrasion resistance, corrosion resistance and fatigue resistance according to the number of revolutions. Various heat treatment methods are used to maintain such mechanical properties. Heat the metal material above a certain temperature, hold it for a certain time, and slowly or quenching it in water or oil. The reason for this is to obtain the mechanical properties desired by the flexibility and compactness of the organization through the process of changing the organization. It can be considered as a process of improving the value of metal materials. It is to utilize it as a part suitable for the purpose of improvement of mechanical performance. The inner race used in this experiment is a part that carries a constant load among the automobile parts and transmits the continuous driving force. Therefore, a more efficient heat treatment method is needed to obtain a certain level of hardness and microstructure. Various alloying elements are added to the steel to change the metal properties. If the alloying element is the same size as the iron atom, it is added through the iron atom and the inversion. However, if the atom is small, like nitrogen, it enters the interstitial site. The alloying elements are added to promote austenite and ferrite stabilization, and carbide formation. As a method for measuring the influence of an alloying element, there is a method of measuring whether the vacancy temperature increases or decreases or does not change with the addition of alloying elements. The austenite stabilizing element also serves to lower the vacancy temperature or broaden the stabilization temperature range. The purpose of this study is to analyze the microstructures of the components of constant velocity joints, called inner lace, on the mechanical properties of the alloying elements and the carbon diffusion. Also, we tried to investigate the carbon concentration and carburizing time by the depth of the specimen through simulation.

II. EXPERIMENTAL METHODS

A. Specimen Preparation

The specimen (SCR-20) is an inner lace, the outer diameter is φ60, the inner diameter is φ29, and the height is 30 mm. The specimens were cut vertically from the surface to the core to observe the texture of the specimens before heat treatment using an optical microscope. After the heat treatment, the specimens were cut vertically from the surface layer in the direction of the depth so as to observe the microstructure due to the influence of alloying elements and carbon. Vacuum wire cutting was performed to minimize the change in hardness and texture state to be measured when cutting the specimen.

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B. Mounting

The mounting was made of synthetic resin. As shown in Fig. 1, the mounting was fixed by showing the vertical face of the test piece, and the thermosetting acrylic resin powder which hardened easily was injected into the heating press and mounted. The test specimens were placed to facilitate grinding and polishing. The specimen was placed in the center on the piston face, the resin material was placed on it, and the cover was covered and fixed. Then, the piston was pressed by operating the hydraulic handle. The mounting was held at 185 ° C for 3 minutes and cooled for 3 minutes.

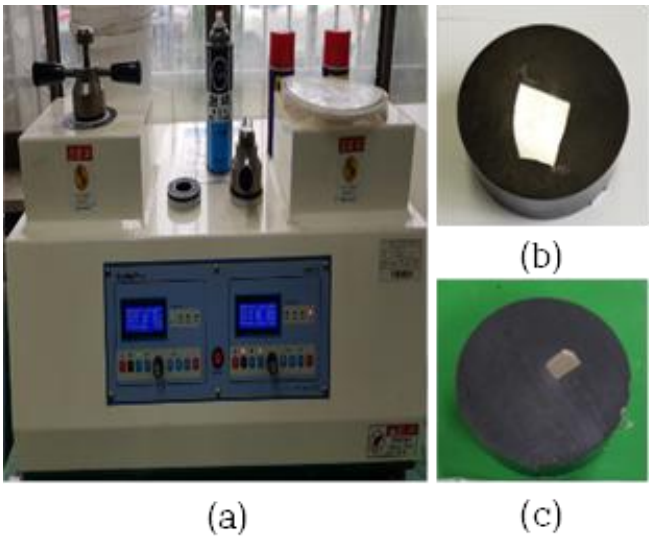

Fig. 1 Mounting press and specimens
Mounting press (b) Specimen before heat treatment
(c) Specimen after heat treatment

C. Grinding

The specimens were polished with an abrasive for inspection. The specimens for the hardness test were roughly polished to make a horizontal plane. As a method of moderately polishing the surface roughness, an abrasive paper coated with a black gray powder abrasive was used. When the intermediate polishing was performed, the stripes on the primary polishing surface were removed while being careful not to be tilted to one side. If the specimen is too strong, the specimen may be heated. Therefore, it is smoothly polished by reciprocating motion so as not to be heated. The abrasives were used in the order of coarse powder abrasive # 120 to fine abrasive # 3000. If the sample was polished until the scratches completely disappeared and then rotated by 90 degrees, the roughness of the test surface gradually became finer. Finally, we used a 1μ diamond surface with excellent abrasiveness for the specimen surface mirroring. This is very useful for making the mirror surface of the surface to be inspected in a short time. In the polishing operation, it is effective to keep the specimen parallel to the three fingers of right hand and to grind it in reciprocating motion on the abrasive paper. The polishing rate was 250-400 mm/s.

D. Elemental Analysis of Alloy Metals

For the test specimens, alloy steel (SCR-20) as shown in Table 1 was used and the composition was analyzed using Brucker X-ray Fluorescence.

E. Heat Treatment Condition

Carburized by gas carburizing method which is easy to control the carburizing concentration and can make the carburizing uniform. The surface of the specimen was carburized at 930 ° C for 10 hours, and the carbon potential was maintained at 0.9 wt%, propane (C_3H_8) gas was 2.5 L / min, and RX-gas was 350 L / min.

Table 1 Chemical composition of Specimen

Elements	**Chemical Composition(wt%)**
C	0.20
Si	0.25
Mn	0.83
P	0.014
S	0.007
Ni	0.06
Cr	1.14

After carburizing, it was maintained at 930 ° C for 3 hours for carbon diffusion. The carbon potential remained 0.75 wt%. Higher carbon potentials do not need to be higher because soot is generated. To miniaturize the structure, quenching was performed at 840 ° C for 30 minutes, and then oil cooling at 130 ° C was performed. Table 2 shows carburizing process and heat treatment condition of the carbon-chromium alloy steel.

Table 2 Heat treatment condition

Carburization process		**Condition**
Carburizing	Temperature	930℃
	Time	10hr
	CP	0.90 wt%
	C_3H_8 Gas	2.5 ℓ/min
Diffusion	Temperature	930℃
	Time	3hr
	CP	0.75 wt%
Quenching Temperature		840℃
Cooling	Method	Oil
	Temperature	130℃

F. Structure and Hardness Examination

In order to analyze the structure changes affecting the hardness of the carbon diffusion, the specimens before and after the heat treatment were observed with an optical microscope at the ratio of 500 times in the order of the surface and inside of the specimen. The effective carburization thickness of the specimen shall be determined by the hardness test. Hardness of each carburizing depth was measured using a micro Vickers hardness tester. The reason for measuring the hardness is to analyze the relationship between the change in carbon content and hardness. Most of the researchers have been studying the fatigue strength characteristics of steels with an effective carburization thickness of 1.5 mm or less. [2] .

G. Simulation Test

The heat treatment carried out to improve the mechanical properties of the automotive parts should be low cost and have the greatest economical effect. Therefore, in order to find the optimal heat treatment conditions, the carburizing depth and the carburizing time of the effective hardening depth were confirmed at various temperatures, carburization and diffusion time, and carbon potential conditions. EUROTHERM S/W (England, Eurotherm Ltd, Version 2.00) was used for the simulation. The simulated conditions were assumed to be effective hardening depth 550Hv at 930 ℃ and target carburization depth 0.5mm, and the carbon composition was aimed at 0.36%. The carburizing carbon potential was simulated by setting 0.85 wt%, 0.9 wt%, 1.1 wt%, and diffusing carbon potential of 0.75 wt%, respectively.

Table 3 Simulation condition

Alloy steels	SCR-20		
Test No.	T1	T2	T3
Heat treatment temperature	930℃		
Curing Depth (0.36%C Point =550Hv)	0.5	0.5	0.5
Carburizing CP	0.85	0.90	1.10
Diffusion CP	0.75		

III. EXPERIMENTAL RESULTS AND DISCUSSION

The inner race, which is the automotive part used as the specimen, is shown in Fig. 2.

Fig. 2 Carburized inner race.

The hardness distribution curves of the specimens at different carburizing depths are shown in Fig. 3.

If the carburizing heat treatment has abrasion resistance and strength is not important, the carburizing depth should be 0.15 mm or less. For parts with high abrasion resistance and high strength, they should be 0.5-1.0 mm. In the case of parts that require strong strength against load such as sliding and rotation, such as inner race, which is a constant velocity joint part, a carburizing depth of 1.0-1.5 mm is required.

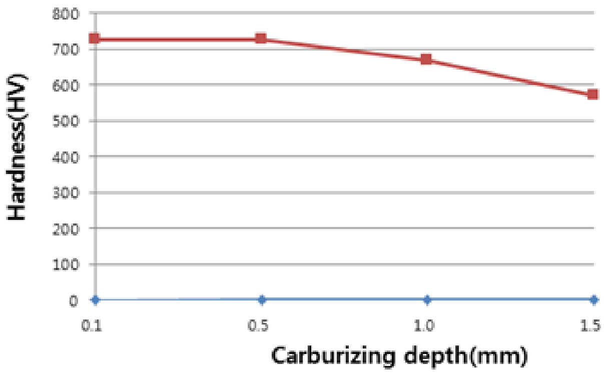

Fig. 3 The carburized hardness distributions of alloy steel.

In this experiment, the carburizing depth of the effective hardening depth 550 Hv was about 1.3 mm.[3]. The Vickers hardness value of the specimens after burning was the highest at 725 Hv at the surface layer of 0.1 mm with a large carburization amount. The carburized amount was 570 Hv at 1.5 mm thickness. And the hardness decreased from the surface to the depth direction. There is a reason for maintaining a constant carbon content of 0.75-0.9 wt% in the study. It is because if more than 1wt% is applied, cracking can occur during part machining. In other words, it does not cause over carburization. [4]. As a result of the test, the effect of carbon diffusion on the surface of the specimen is very large and is considered to be closely related to carbon diffusion rate, temperature, and diffusion holding time [5,6]. The metal structure of the carburized steel is closely related to the strength of the carburized layer. During the structure examination, the desired mechanical

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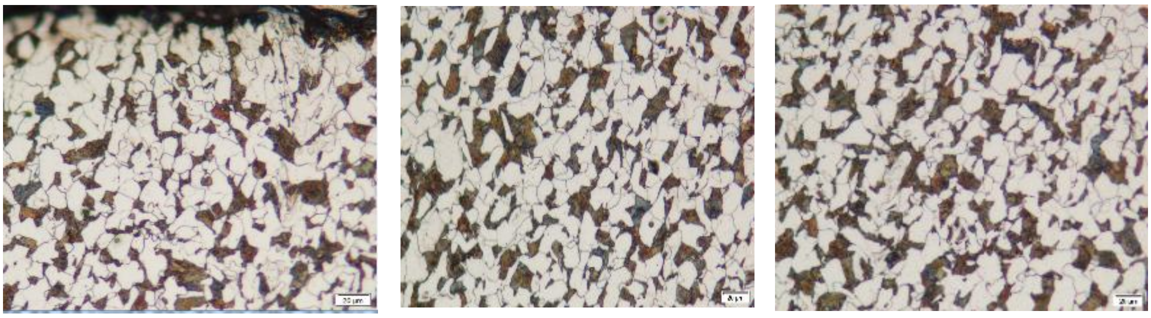
properties cannot be obtained when the ferrite and pearlite structure are not completely transformed into martensite during the heat treatment and a part of the retained austenite is present. In the heat treatment, a trace amount of oxygen reacts in the gas atmosphere to form oxides in the grain boundaries, which may cause fatigue fracture. In some cases, the formation of oxides reduces the alloying elements around the grain boundaries to weaken the steel material. As shown in Fig. 4, the metal structure before the heat treatment was observed. As a result, a mixed structure of perlite and ferrite appeared.

The grain size of the test specimen was uniformly distributed. However, as shown in Fig. 4 (a), it was confirmed that after carburizing, the austenite was transformed into martensite. In addition, some residual austenite was present in the tissue after the heat treatment. The matensite structure, which is the ideal tissue metamorphosis of inner race components, was uniformly distributed. Fig. 4 (b) shows that most of them are transformed into martensite.

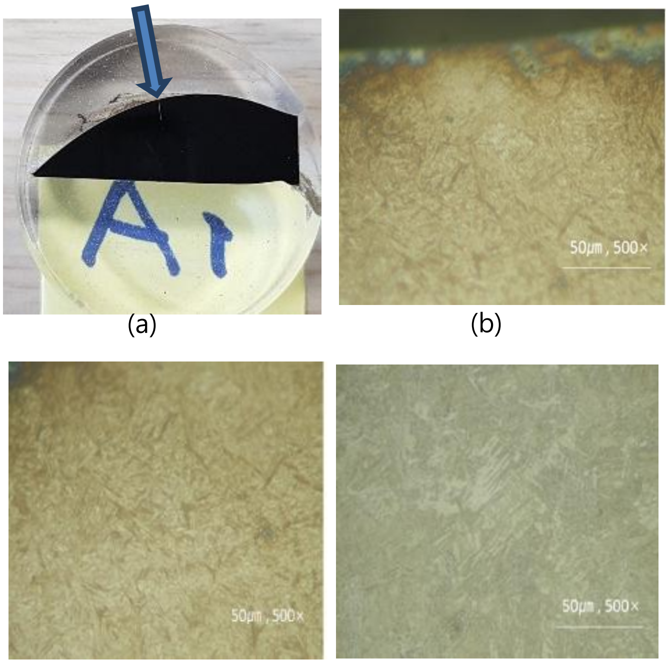
Some residual austenite and bainite structures were also observed in Fig. 4 (c). In the center of Fig. 4 (d), the microstructure before the carburization was not carburized, but the microstructure before the transformation was transformed during the heat treatment and the ferrite before the transformation was also observed during the oil cooling.



(a) (c) (b)

Fig. 4. Optical microscope photographs : before carburizing of alloy steel[x500].
(a) Surface (b) Surface carburizing layer (c) Center

It is difficult to define perfect phase because it is difficult to distinguish from martensite[7,8]. Cr alloyed steels may have excellent hardenability[9], but it is necessary to lower the carbon potential since carbides can be formed.[10,11]. The measurement site is shown in Fig. 5 (a).



(a) (b) (c) (d)

Fig. 5 Optical microscope photographs : Carburized alloy steel[x500].
(a) Specimens (b) Surface (c) Surface carburizing layer (d) Center

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Fig. 5 (b), 5(c), 5(d) are shown surface, near surface, center of carburized alloy steel.

The simulation results of the carburizing condition and the carburizing time of the inner race, which is an alloy steel, are shown in Fig. 6. The simulation was performed under the following three conditions. Fig. 6 (a), (b) and (c) show the results of simulations for determining the curing depth of 0.36% C, which corresponds to the effective curing depth 550Hv, at carburizing and diffusion temperature of 930 ℃ for 10 hours and 3 hours of diffusion. Simulation results show that the carburizing depth is 1.398mm and 0.36% C, which corresponds to the effective hardening depth 550Hv, when the carburizing CP is 0.85wt% and the diffusion CP is 0.75wt%. In the case of Fig. 6 (b), the carburizing depth is 1.467mm and the effective hardening depth is 550Hv, which is 0.36% C, when the carburizing CP is 0.9wt% and the spreading CP is 0.75wt%. In case of (c) in Fig. 6, the carburizing depth was 1.725mm and the effective hardening depth was 550Hv, which was 0.36% C at 1.1 wt% of carburizing CP and 0.75 wt% of diffusing CP.

Simulation results show that the higher the carbon potential at carburizing, the better the carburization diffusion and carburization from the surface to the deeper part.

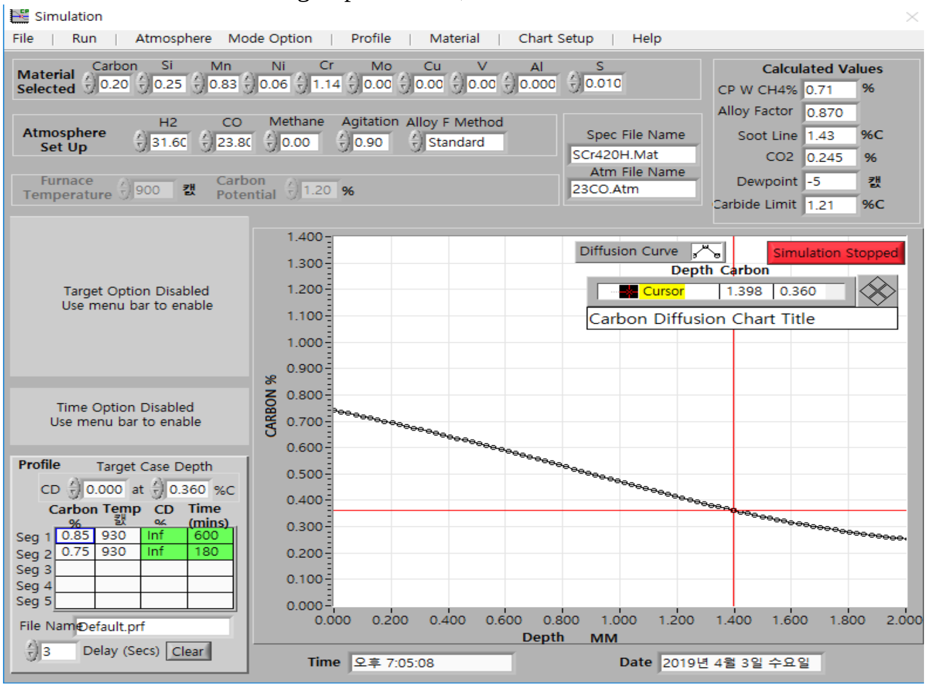

Fig. 6(a) Carburizing CP 0.85wt%, Diffusion CP 0.75wt% (T1).

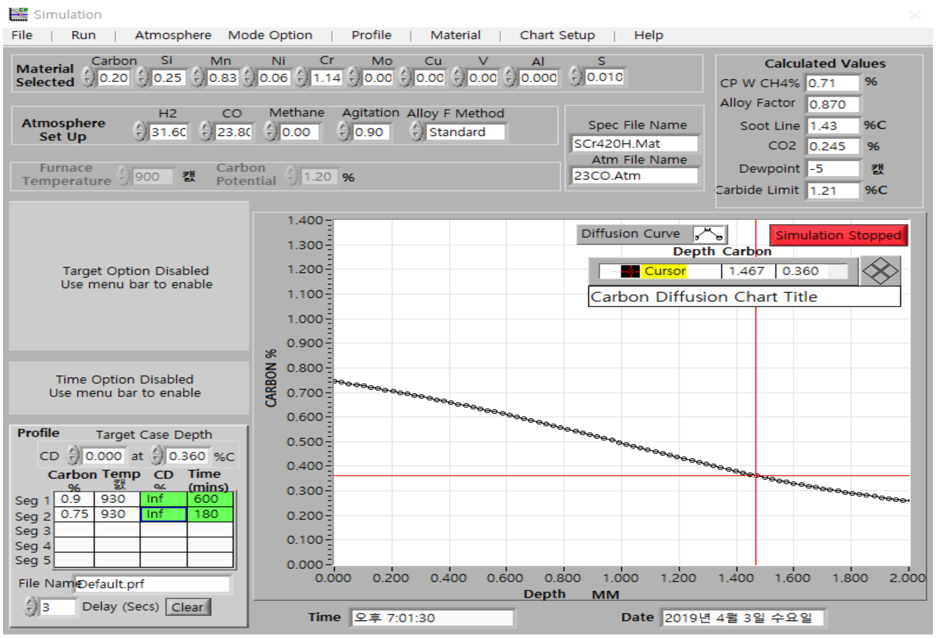

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Fig. 6 (b) Carburizing CP 0.90wt%, Diffusion CP 0.75wt% (T2).

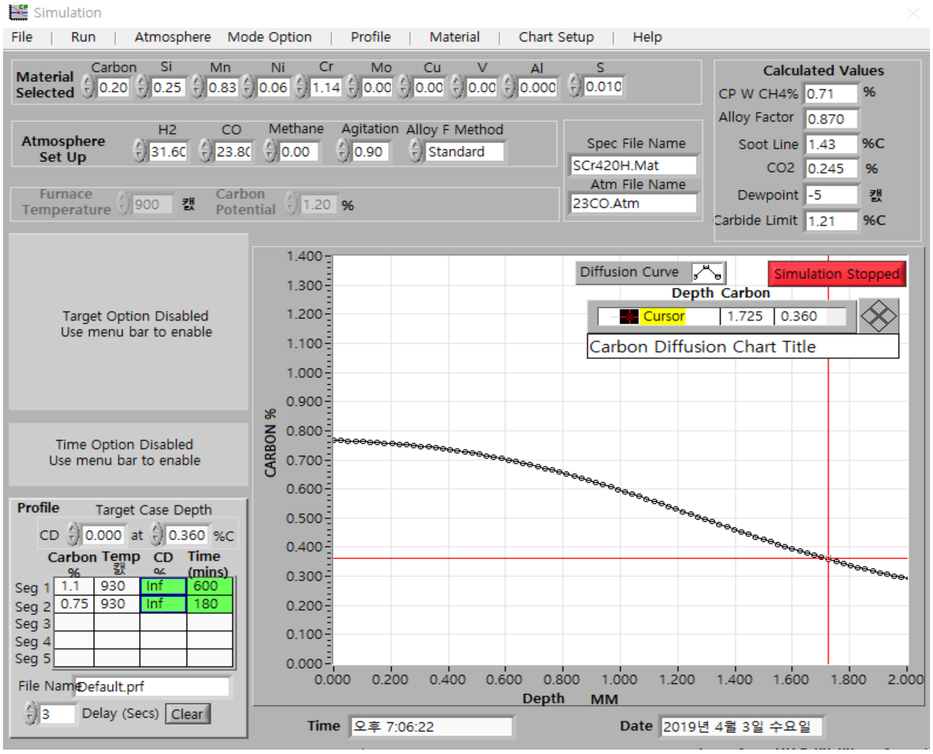

Fig. 6 (c) Carburizing CP 1.10wt%, Diffusion CP 0.75wt% (T3).

Fig. 6 Effect of carbon potential on carburization and carburizing depth.

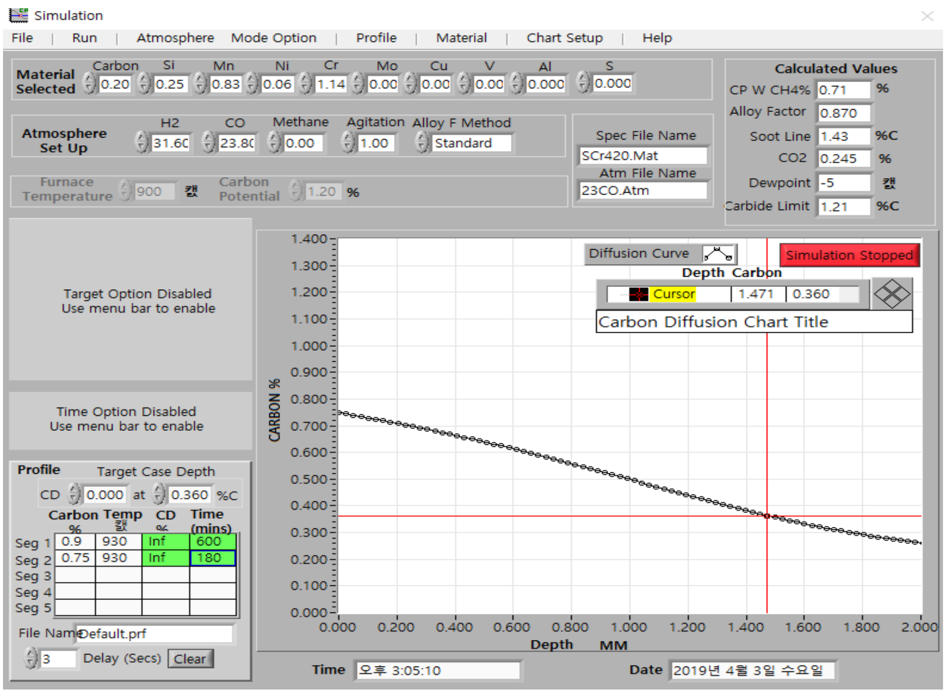

Fig. 7 (a) Actual carburization amount and carburization depth.

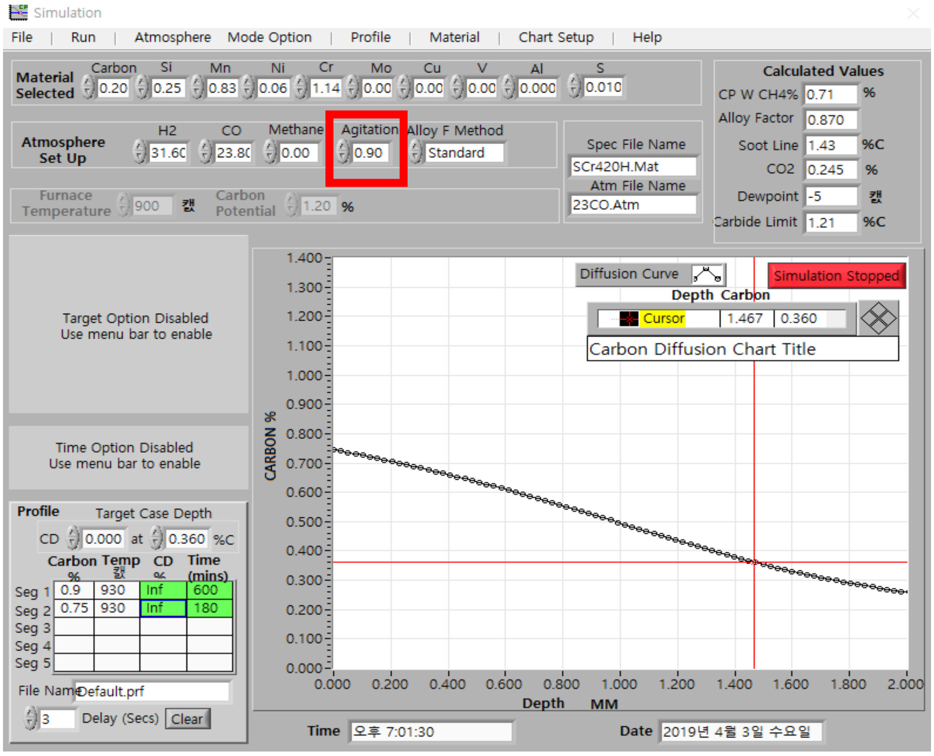

Fig. 7 (b) Carburized amount and carburizing depth from simulation data.

Fig. 7 Comparison of actual carburization between simulation results of inner race.

Fig. 7 (a), 7 (b) show the comparison between actual carburization conditions and results of the inner race for constant velocity joints and simulation results. Carburizing and diffusion Temperature of 930 ℃ for carburizing 10 hours and 3 hours of diffusion showed that the hardening depth of 0.36% C corresponding to the effective hardening depth 550Hv was not significantly different from the actual and simulation results. However, as a result of hardness test, it was found that the agitation constant value should be 1.0 in the actual carburizing products in order to obtain the hardening depth of 1.467 mm by matching the hardening depth of 0.36% C at 550 Hv to the target value,. As shown in Fig. 7 (a), when the carburizing CP was 0.9 wt% and the spreading CP was 0.75 wt%, the carburizing depth was 1.471 mm, which was 0.36% C corresponding to the effective curing depth 550Hv. However, in simulation, as shown in (b), when the carburizing CP was 0.9 wt% and the spreading CP was 0.75 wt%, the carburizing depth was 1.467 mm and 0.36% C corresponding to the effective hardening depth 550Hv was obtained. The actual carburizing depth of 0.36% C, which corresponds to the effective hardening depth 550Hv, was found to be 0.004 mm in comparison with the simulation results, but it was necessary to correct the Agitation constant value to 0.9 in order to obtain almost similar results.

IV. CONCLUSION

The aim of this comparative study was to investigate the optimum heat treatment conditions, the effect of carbon on heat treatment, and the effect of alloy composition. The results showed that carbon diffusion affected the hardness of the chromium alloy steel specimens.

Observation of the optical microscopic structure showed that the mixed structure of pearlite and ferrite was transformed into martensite structure which is mostly layered structure in pre - carburized structure.

The heat treatment to obtain the mechanical properties of the inner race used in a constant velocity joint for automobiles should be carried out at a carburizing and diffusion temperature of 930 ℃ for 10 hours of carburizing and for 3 hours of diffusion.

The amount of carburization corresponding to the effective hardening depth 550Hv was 0.36% and the hardening depth was 1.467mm. There is no significant difference between actual carburization and simulation.

In order to obtain the available effective carburizing depth and carburizing amount and the curing depth of 1.467 mm, the Agitation value should be set to 1.0 in actual carburizing but it should be corrected to 0.9 in the simulation.

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