Analysis on the Microstructure and Hardness Change After Carburizing of Chromium-Molybdenum Alloy Steel for Automobile Parts

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

Abstract*: *This study is to investigate the influence of gas carburizing heat treatment on an automatic transmission oil pump drive hub and an engine crankshaft sprocket, which are automotive parts using chrome-molybdenum alloy steel. The main focus is to investigate the effects of carbon potential, carburization time and diffusion time on surface hardness of automotive parts specimens. The test specimens used were made of actual models and sizes of automobile parts. Carrier gas was produced by introducing RX gas mixed with propane and air. The carburizing process was divided into two stages for carburization and diffusion. The results show that the lower the carbon content, the shorter the carburization time and diffusion time required to reach the required surface hardness and internal hardness. It is judged that this is related to the diffusion gradient of carbon on the surface and inside of the material. After the heat treatment, the surface structure was martensite and the internal structure showed a mixed structure of pearlite and ferrite. The hardness according to the carburizing depth of the heat treated parts was measured using a micro Vickers hardness (HV 550) tester. As a result of the analysis of the specimen which was carburized from carbon content 0.20% Oil pump drive hub and 0.15% Crankshaft sprocket prototype, the carbon potential was high, the carburization time was longer and the surface hardness was high. Also it was found that the Carburizing time and carbon potential were found to have a greater effect on carburization hardness than carbon content.

Index Terms*: *Chromium-molybdenum alloy, Gas carburizing, Crankshaft sprocket, Oil pump drive hub, Carbon potential.

I. INTRODUCTION

The development of the automotive industry basically requires improved durability of parts. Recently, interest in the automotive field is actively being researched worldwide for the development of artificial intelligence autonomous vehicles, which are key technologies in the 4th industry. In addition, the engine which is core of automobiles is being developed from power supply through fossil energy to alternative energy supply through electricity and hydrogen. Because the current engine will continue to be used for quite a time even if the energy source is replaced, the automobile parts to be tested are inevitably used. Satisfied with the miniaturization and weight reduction of automotive parts and to secure sufficient durability and reliability, it is necessary to increase the strength of the automobile parts. So the carburizing heat treatment is used [1]. Automobile parts are applied heat-treating technique for a high level of wear resistance and corrosion resistance, improved fatigue resistance and so on. The basic methods of heat treatment are carburizing and nitriding. Such a heat treatment method includes a heat treatment method of simultaneously impregnating at a constant temperature, a carburizing treatment in a low vacuum non-oxidizing atmosphere state capable of carburizing in a short time, and the like. Also, nitriding method for heat treatment of steel at low temperature using NH_3 and endothermic gas, Oxynitriding method in which Fe_3O_4 is generated on the surface of a compound layer by simultaneously injecting a nitriding gas and a sedimentation gas, plasma nitriding method of controlling nitriding characteristics, a low-pressure nitriding method in which ammonia and nitrogen dioxide gas are used in a low-pressure vacuum to obtain a high hardness and abrasion resistance It is used actively. Carburizing heat treatment of steel is a technique to control carbon, which is a heat treatment to produce martensite as main microstructure by controlling carbon amount by carburizing and then quenching. At this time, the amount of carbon is maintained in the range of 0.7 to 0.8wt%. When a steel having a carbon content of 1wt% or more is quenched, martensite and a large amount of retained austenite, carbide mixed structure are produced. A material having increased brittleness by carbide and retained austenite tends to be cracked during polishing [2]. The gas carburizing heat treatment among the carburizing heat treatment is a process of quenching and tempering low carbon steels where the carbon content of the surface was increased through the heat treatment in the carburizing atmosphere which made by burning the hydrocarbon gas in the austenite single phase region(850 to 950°C). The maximum high capacity of carbon in the austenite area increases from 0.8 wt% to 2 wt% depending on the temperature. As a result, a high-carbon martensite layer having high abrasion resistance and high fatigue resistance formed on the internal structure and the diffusion layer with good ductility by diffusion of carbon from the

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surface to the inside improves the mechanical performance [3, 4]. In this study, the pump drive hub and the engine crankshaft sprocket specimen of the automatic transmission oil pump drive system were tested which are used in the actual car parts. The sprocket is mounted on the crankshaft of the engine. The appearance is saw tooth, sometimes a pulley is used instead of a saw tooth type. The function of sprocket is to transfer the power of the crankshaft to other parts using a chain or belt. Also, the drive hub which is a part of the oil pump drive supply oil to cool the heat generated by each component of the automatic transmission. It is an automatic transmission parts that supports the pump shaft and holds it in a fixed position. The material of these test specimens wear made of carbon-molybdenum alloy steel and produced by cold forging. These parts can improve the automobile power and fuel economy, but can easily be destroyed. Therefore, the surface of the product is required to have high hardness and toughness, and wear resistance, fatigue strength, impact resistance and the like must be high as well. In order to maintain such mechanical properties and high hardness and toughness of the surface and to prevent delayed fracture, it is generally used after carburizing and an anti-carburizing or a tempering is applied [5, 6]. Therefore, carburizing heat treatment is required to satisfy these properties. In order to satisfy these characteristics, it is necessary to study the factors affecting various effects such as the optimum carburizing condition of Chromium- molybdenum alloy steel. Also, these factors include carbon potential, carburizing material, carburization holding time and diffusion time. The next [Fig. 1] show carburized specimen of oil pump drive hub and crankshaft sprocket. Therefore in this study, the change in hardness value according to depth was measured by observing the test piece cutting into the minimum diameter portion after the heat treatment of the gas carburization using an optical microscope and a scanning electron microscope [7]. In addition, when carburizing with specimen of actual product, the suitable heat treatment conditions, the distribution of hardness according to the carburizing depth and the microstructural changes of the surface and internal structure required for the product were investigated.

(a) Oil pump drive hub

(b) Crankshaft sprocket

Fig. 1. Carburized automotive parts

II. EXPERIMENTAL METHODS

A. Analysis and Preparation of Specimen

The chromium-molybdenum alloy steel used in carburizing test were SCM-20(Oil pump drive hub) and SCM-15 (Crankshaft sprocket) used for automotive parts. The chemical composition of the specimens was analyzed by Brucker X-ray Fluorescence (WD-XRF Tiger). Table 1 below shows the analyzed composition values.

Table 1. Chemical composition of specimens

Elements	Chromium-molybdenum alloys	
	SCM-20	SCM-15
C	0.200	0.150
Si	0.260	0.250
Mn	0.820	0.830
P	0.015	0.014
S	0.007	0.006
Ni	0.090	0.080
Cr	1.120	1.130
Mo	0.190	0.200

Changes in hardness and texture of the specimens were measured and analyzed before and after the heat treatment. The test pieces used in this experiment were the automotive automatic transmission oil pump drive hub and engine crankshaft sprocket parts subjected to the process of cold forging. For obtaining the minimum hardness value required for automobile parts, cutting and collecting in a cross section were performed after carburizing heat treatment. The mounting procedure was performed to obtain a flat surface for easy measurement, and grinding and polishing were carried out. Cutting of specimens was done by wire cutting to minimize changes in hardness value due to heat. The mounting was resin mounting which placing a specimen at the center of the piston face, inserting powdered resin material, and heat pressing it with a piston. And, the mounting was made of mold entirety temperature was 185℃, holding time was 3 minutes and cooling time was 3 minutes. The Fig. 2 show mounting press and mounted specimens.

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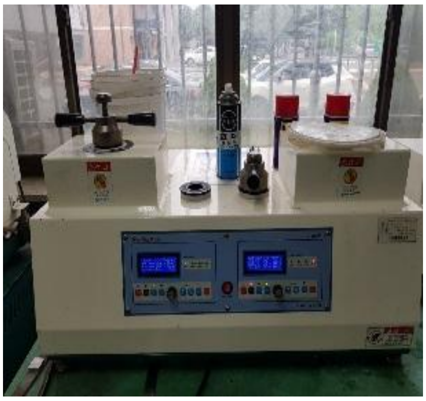
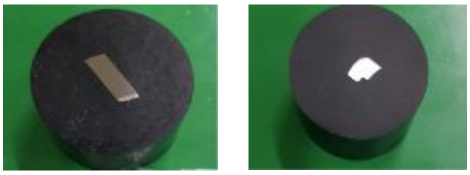
In order to minimize surface scratches after mounting, rough polishing and intermediate polishing were performed in the order of # 220, # 800 and # 2000.

After that, the surface of the specimen was cleaned by using a 1μm diamond useful paste at 200rpm with a polishing machine(220V/1PH) with synthetic fibers electrodeposited and soft pores. For identification of metal tissue by scanning electron microscope(SEM), coating was performed with platinum(Pt) for 1 minute.



(a) Mounting press

(b) Mounted specimen



(c) Mounted specimen

Fig. 2. Mounting equipment and mounted test specimens

B. Heat treatment and simulation

The pump-driven hub specimen (SCM-20) cold-rolled with chrome-molybdenum alloy steel has an outer diameter of φ 124, an inner diameter of φ 36 and a height of 37 mm, and the crankshaft sprocket (SCM-15) has an outer diameter of φ 45, an inner diameter of φ 37, and a height of 20 mm of you have a shape. For use as automobile parts, the effective carburizing depth of SCM-20 should be in the range of 0.8~1.2 mm based on 513Hv of micro Vickers hardness, and the effective carburization depth of SCM-15 should be in the micro Vickers hardness of the have range 0.2~0.45 mm based on 550Hv. In order to meet these conditions, simulation was performed with the program shown in the [Fig. 3].

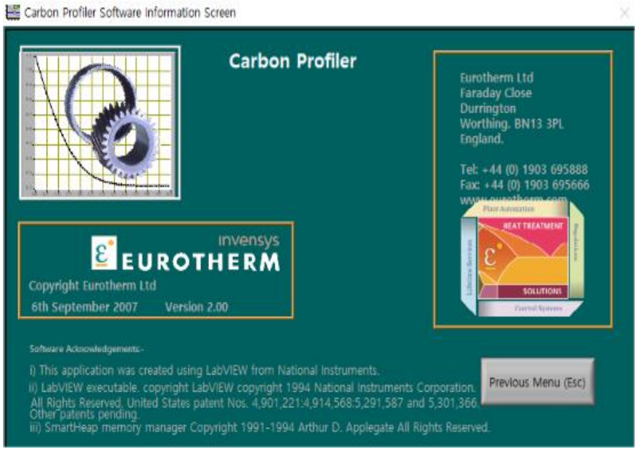
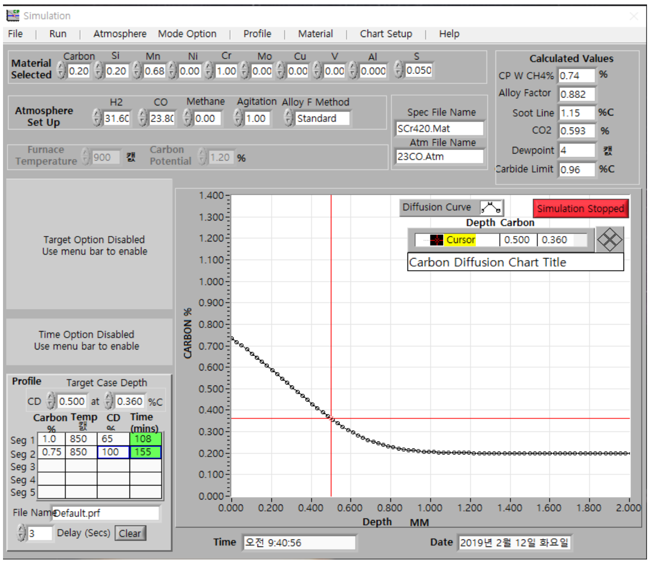
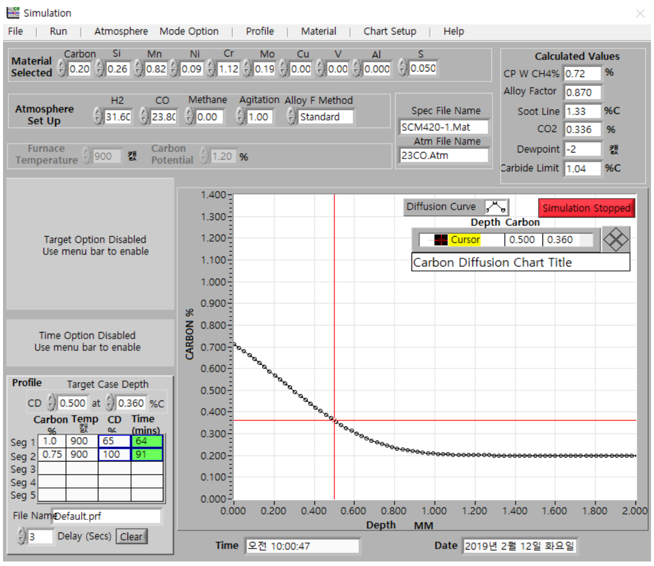


Fig. 3. Carbon Profiler Software Information Screen.



(Fig. 4-a, 850℃)



(Fig. 4-b, 900℃)

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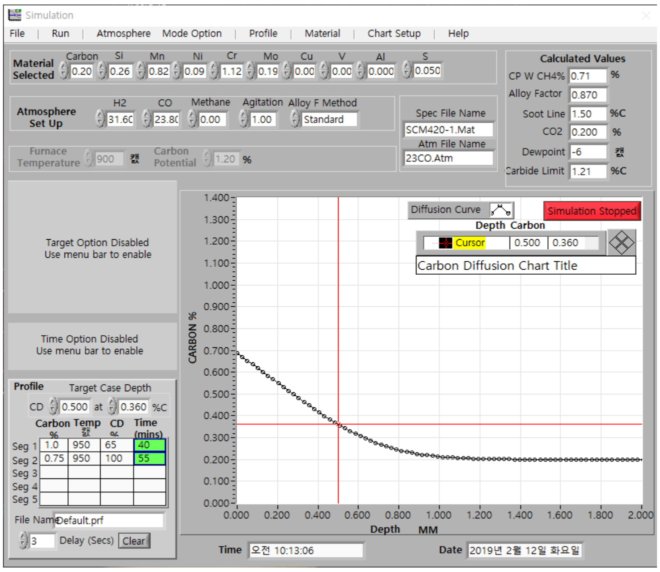
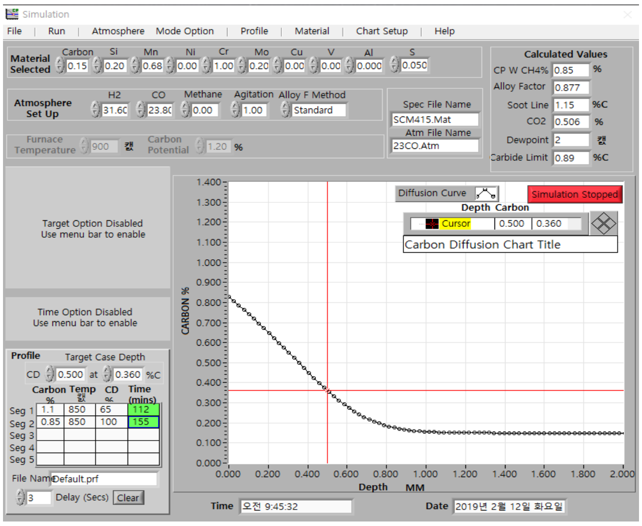


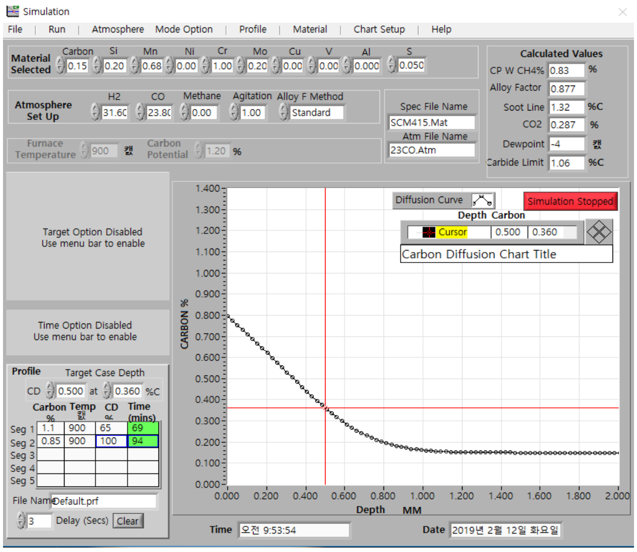
(Fig. 4-c, 950℃)

Fig. 4. Simulation of SCM-20 at the carburizing temperature.

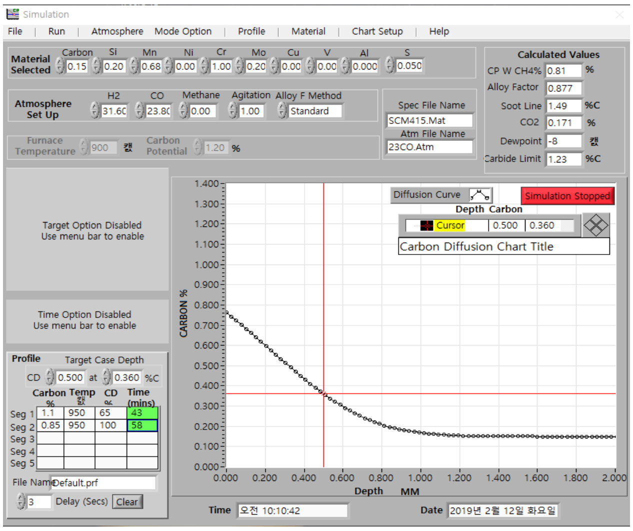
Simulation was performed as shown in [Fig. 4-a, 4-b, 4-c, Fig. 5-a, 5-b, 5-c,], with various conditions being changed after entering the basic conditions in the program.



(Fig. 5-a, 850℃)



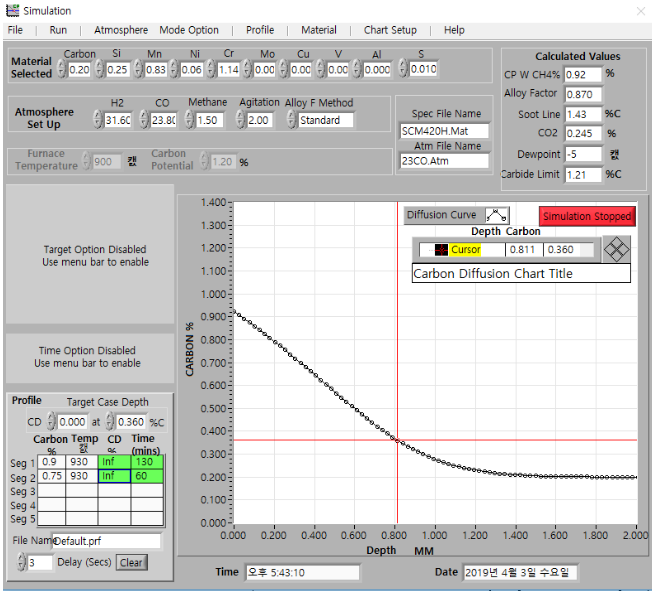
(Fig. 5-b, 900℃)



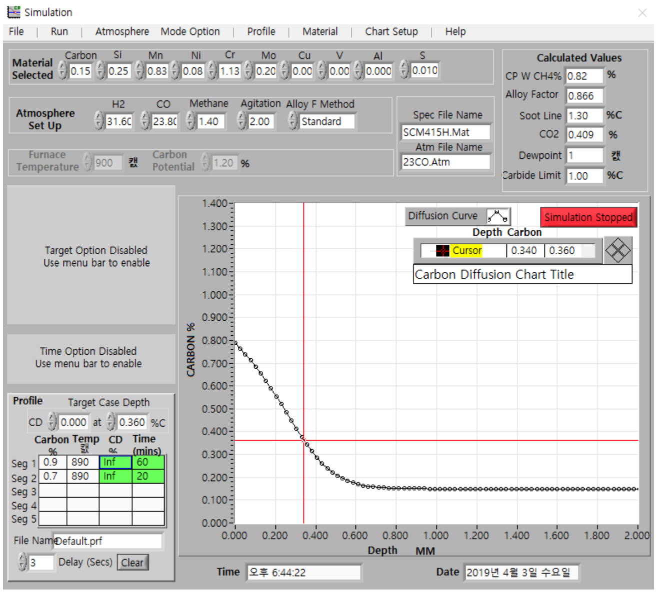
(Fig. 5-c, 950℃)

Fig. 5. Simulation results of SCM-15 at the carburizing temperature.

As shown in the simulation results in [Fig. 6-a, 6-b] , the carburizing temperature was 930 ° C, the carburizing time of SCM-20 was 2 hours, the SCM-15 was one hour, and the optimum carbon potential was 0.9 wt%. The diffusion conditions of SCM-20 were 1 hour at 930 ° C and 20 minutes at SCM-15, and the carbon potential was 0.75 wt%.



(Fig. 6-a, SCM-20)



(Fig. 6-b, SCM-15)

Fig. 6. Simulation results at carburizing temperature 930℃.

Therefore, the carburizing temperatures for penetrating the specimen surface at 930 ° C were 2 hours for SCM-20 and 1 hour for SCM-15. The carbon potential should be maintained at 0.9 wt%, and the amount of propane gas (C_3H_8) injected was 3.0 L / min.

RX-Gas maintained 350L/min until carbon diffusion. The carbon potential was maintained constantly for distributing the carburizing gas evenly on the specimen. Since hydrocarbons were introduced during the carburization, the experiment induced simultaneous carburization of several gases such as 2CO ↔ CO_2, CO+H_2 ⇆ C+H_2O, C_3H_8 ⇆ C+2CH_4.

Andakso, for the carbon diffusion, the diffusion temperature was 930℃. Duration time were 1hr and 20min. in the SCM-20 and SCM-15. Carbon potential was maintained at 0.75wt%. In order to minimize specimen deformation and to refine the structure, quenching was carried out at 830℃ for 30 minutes and then oil quenching was carried out at 130℃. Fig. 7 shows the heat treatment process consisting of preheating, heating, carburizing, diffusion, furnace cooling and oil quenching of SCM-20 and SCM-15.

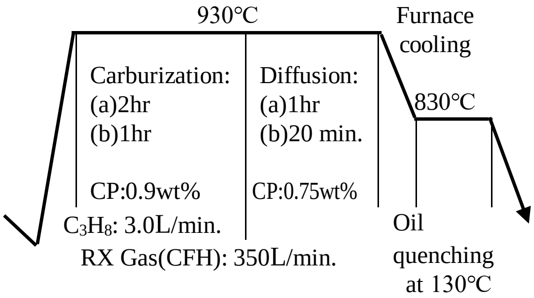
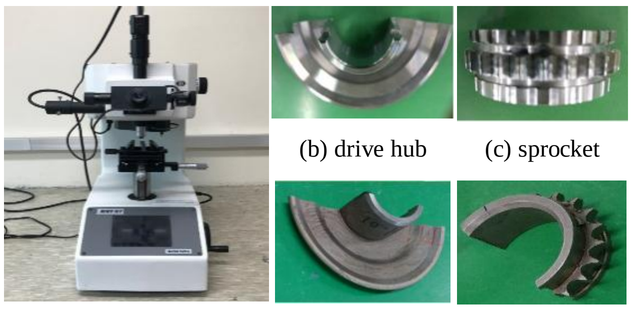


Fig. 7. Gas carburizing cycle. (a)SCM-20, (b)SCM-15(CP: Carbon potential).

C. Hardness measurement of specimen

The heat-treated specimens and form a hardened layer, where by the effective thickness of the carburization is determined by the hardness test. In the KS D ISO 4507, the point on the curve corresponding to 550Hv is defined as the effective carburizing thickness by the Vickers hardness test method [8]. The specimens of the oil pump drive hub and the crankshaft sprocket used as automobile parts were measured and analyzed by hardening depth with a micro Vickers hardness tester before and after the carburizing [Table 2]. In addition, Fig. 8 shows the hardness tester and the experimental cut test specimen.



(b) drive hub (c) sprocket

(a) Hardness tester (d) drive hub (e) sprocket

Fig. 8. Hardness tester and specimen. (a): Hardness tester (MMT-X3), (b, C): drive hub and sprocket of before carburizing sprocket, (d, e): drive hub and sprocket of after carburizing.

The test piece cut to a proper size was polished by rough polishing, intermediate polishing and fine polishing after resin mounting thereby minimizing the surface roughness to the utmost. In order to determine the hardness change with depth in the carburization specimen, it was performed by using a micro-Vickers hardness tester and hardness was measured constantly at a load of 1000g and a load time of 10 seconds in the depth direction from the surface. The average hardness was measured 10 times at each depth and were carried out at different sites within same material two measurements [3].

D. Microstructure analysis

Generally, the reason for the heat treatment is to improve the mechanical properties such as abrasion resistance and fatigue resistance on the surface by carburizing carbon in the steel. Therefore, in this study, the microstructural changes affecting hardness of carbon and other elements in SCM-20 and SCM-15 specimens were analyzed. Before and after the heat treatment, the specimens were etched with 5% Nital solution for 8 seconds, then observed by optical microscope at a magnification of 500 times and observed with a scanning electron microscope at a magnification of 2000 times it is constant interval.

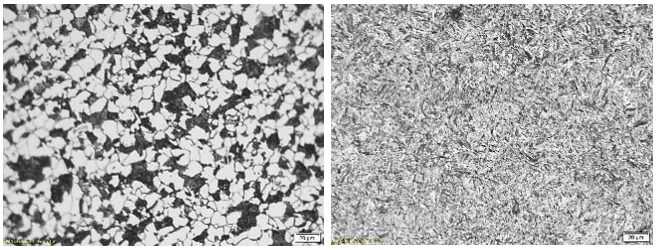
(a) Optical microscope (b) SEM

Fig. 9. Optical microscope and scanning electron microscope (SEM). (a): Optical microscope (OLYMPUS, BX51M), (b): Scanning electron microscope (HITACHI, S-3000H)

The main purpose of this study was to investigate the relationship between the formation of surface abnormal layer, the change of texture on the hardness by depth of carburization, the formation of inter-granular oxide, the change of carbon content and hardness. Fig. 9 show optical microscope and scanning electron microscope for micro-structure analysis of carburized specimens.

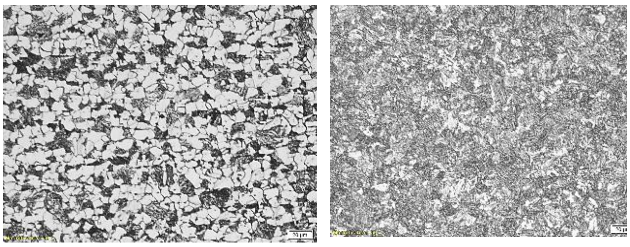
III. EXPERIMENTAL RESULTS AND DISCUSSION

As shown in [Fig. 1, 8], carburizing specimen of automobile parts in the automatic transmission oil pump drive hub and engine crankshaft sprocket was used. In this study, the carbon potential was maintained at 0.75-0.9 wt%. When 1 wt% or more is quenched, martensite structure is formed. Further, if a mixture of a large amount of retained austenite and carbide is formed, the brittleness increases and cracking may occur during processing. Therefore, it was intended to prevent excessive carburization [8]. The carburization and diffusion time reaching the hardness required in the chrome alloy steel was 0.2wt%, which is about 1/3 of the carbon. These results are considered to be related to the carbon diffusion gradient on the surface and inside of the material [9, 10]. In case of SCM-15, although the carburizing time is short, it is considered that the higher hardness is due to the higher carburization and diffusion temperature of 930°C. The specimen texture before the carburizing heat treatment was observed to be a mixed structure of pearlite and ferrite. After carburizing, it was confirmed that the austenite was transformed into martensite and some of the retained austenite was present. The needle-like structure tended to decrease gradually from the surface to the inside. Most needle-like structure are judged to be martensite. The microstructures of SCM-20 and SCM-15 are shown in Fig. 10 and Fig. 11.



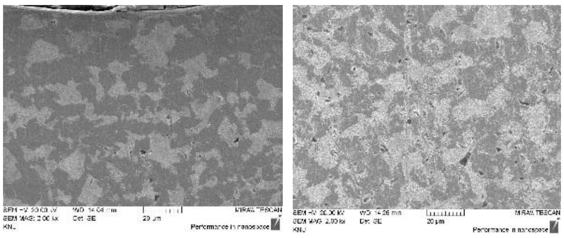
(a) before carburizing (b) after carburizing

Fig. 10. Microstructure photograph of SCM-20 (x 500). (a) before and (b) after carburizing of oil pump drive hub



(a) before carburizing (b) after carburizing

Fig. 11. Microstructure photograph, SCM-15 (x 500) (a): before carburizing of Crankshaft sprocket, (b): after carburizing of Crankshaft sprocket.



(a) surface (b) inside

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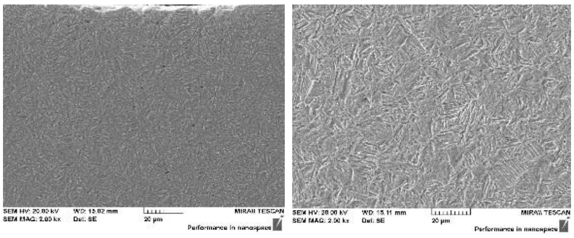
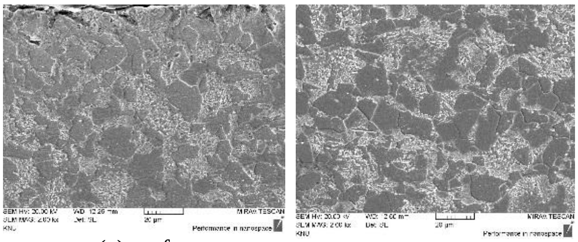
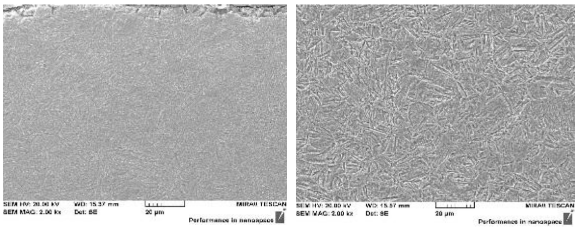


(c) surface (d) inside

Fig. 12. SEM microstructure photographs of SCM-20, (x 2000)
(a), (b): before carburizing, (c), (d): after carburizing.



(a) surface (b) inside



(c) surface (d) inside

Fig. 13. SEM microstructure photographs of SCM-15, (x 2000)
(a), (b): before carburizing, (c), (d): after carburizing.

Fig. 12 and 13 show that pearlite and ferrite exist uniformly in the microstructure of SCM-20 and SCM-15 before carburizing. In the organization photographs of Fig. 10, 11 and Fig. 12, 13 (b), and (c), trace amount of oxygen in the gas atmosphere during carburizing heat treatment was combined with strong affinity with oxygen strong affinity Si, Mn, Cr, etc., have it is combination. The surface layer showed inter-granular oxides which cause fatigue failure. In the gas carburizing heat treatment, RX gas used by modifying propane and butane with air contains trace amounts of water vapor and carbon dioxide gas.

Therefore, this gas is considered to be oxidized by oxygen bonding as carburization progress [9]. This causes deterioration of fatigue resistance and wear resistance. The grain boundary oxidation is inevitable in the gas carburization process, and the Cr and Mn concentrations in the surface layer decrease, which causes the surface hardening and hardenability to deteriorate. After the heat treatment, the carburized compound was observed on the surface and the needle-like compound was mixed therein. The needle compound is judged to be a martensitic structure [10, 11].

Table 2. Hardness change with carburizing depth.

Carburizing depth(mm)	Hardness (HV)	
	SCM-20	SCM-15
0.1	741	739
0.2	734	730
0.3	728	627
0.4	702	535
0.5	656	450
0.6	602	400
0.7	539	392
0.8	530	-
0.9	509	-
1.0	499	-
1.1	480	-

Table 2 shows the change in hardness with depth of specimen material and carburizing depth. As a result of hardness measurement, the hardness value was decreased from the surface to the depth direction as shown in Table 2. As a result of Vickers hardness measurement after carburization, the SCM-20 showed the highest micro-vickers hardness value of 741Hv at 0.1mm, which is a large amount of carburizing, and 470Hv at 1.5mm thickness, which has small carburizing amount. In case of SCM-15, the micro-Vickers hardness value was highest at 739Hv at the surface layer of 0.1 mm, and carburized to 0.7 mm from the surface. The Vickers hardness was 392Hv. If the effective hardening depth by carburization is based on the Vickers hardness of 550 Hv, it can be seen that the value of the SCM-20 test piece is 0.96 mm is the effective hardening depth and the value of the SCM-15 test piece is 0.37 mm is the effective hardening depth [7]. Since

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the SCM-15 test specimens have high surface hardness, the carburizing time satisfying the product standard (HV 700-840) was one hour. Because internal hardening is not necessary, so a diffusion time of 20 minutes is sufficient.

IV. CONCLUSION

In this study, an experiment was conducted to find the optimal conditions for gas carburization to improve the durability of chromium-molybdenum alloy steel, which is a material used for automotive parts. The microstructure before and after carburization of chromium - molybdenum alloy steel was observed by optical microscope and scanning electron microscope. As a result, the microstructure showed before carburization was composed of pearlite and ferrite mixed structure. After the carburization, the needle - like structure tended to gradually decrease from the surface to the interior. And some retained austenite was present, but most of the needle - like structure was transformed into martensite structure. The internal structure showed a tendency of decreasing martensite from the surface, which showed that the toughness is higher than the hardness. In order to shorten the carburization time and the diffusion time in terms of economy, it is considered that carbon should be stabilized by increasing the carburizing temperature and increasing the carbon potential by adding propane gas to the RX-gas. The surface hardness of the chromium-molybdenum alloy steel is strongly influenced by the carbon content. The higher the carburizing amount, the higher the hardness of martensite. However, since a large amount of retained austenite is generated, proper carburization time and diffusion will be required. The results of hardness measurement showed that the hardness value decreased from the surface toward the deep direction. When the effective hardening depth by carburizing is based on Vickers hardness of 550 Hv, it can be seen that 0.96 mm is effective hardening depth for SCM-20 test piece and 0.37 mm is effective hardening depth for SCM-15 test piece. Also, the surface hardness of the SCM-20 specimen was 761 Hv and the SCM-15 was 750 Hv, which satisfied the required hardness value of 700 ~ 840 Hv. The center hardness values were 586 Hv for SCM-20 and 561 Hv for SCM-15. As a result of the comparison with the carburizing test results, it was necessary to adjust the correction factor according to the amount of methane in the propane gas, the amount of agitation, the amount of batch, and the shape of the specimen. In the future, we will analyze the effect of retained austenite on surface hardness and the effect of various carbides on hardness and texture.

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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