International Journal of Engineering & Technology, 7 (3.24) (2018) 296-299

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Carburizing Surface Properties of Chromium-Molybdenum Alloy Steel for Automotive Crankshaft Sprocket and Pump Drive Hub

Choon Yoo[1], Sang-Jin Yoon[*2], Chang-Yeol Oh[3], Bo-An Kang[4]

[1]Dept. of Mechanical Eng., Nambu University, Gwangji, Republic of Korea
*[*2]Dept.of Mechanical Eng., Nambu University,Gwangji, Republic of Korea*
[3]Dept. of Mechanical Eng., Nambu University,Gwangji, Republic of Korea
[4]Dept.of Mechanical Eng., Nambu University, Gwangji, Republic of Korea
**Corresponding author E-mail: sjyoon@nambu.ac.k*

Abstract

The purpose of this research was to investigate the affecting carburization of on the gas carburizing heat treatment layer of each material in the crankshaft sprocket and pump drive hub parts made of chromium-molybdenum alloy steel that are currently used in automobile engines. The effect of carbon potential, carburization time and diffusion time on surface hardness was mainly investigated.The specimen was the same size as the actual model used for the automobile parts and the carrier gas was made by injecting RX gas mixed with propane and air.The propane and butane gas were mixed and injected to control the carburizing gas environment, the steps divided into heat treatment for carburization and diffusion.The hardness of the carburizing depth of the heat treated automobile parts was measured with 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.From these 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. These are considered to be related to the carbon diffusion gradient on the surface and insideof the material.Also it was found that the carburization time and the carbon potential greatly affected the carburization hardness more than the carbon content. After the heat treatment, the surface texture was martensite and the internal structure showed a mixed structure of pearlite and ferrite. These results will be applied factory scale.

Keywords: Chromium-molybdenum alloy, Gas carburizing, Crankshaft sprocket, Pump drive hub, Carbon potential, Surface hardening

1. Introduction

The advancement of the automobile industry requires improvement of the durability of parts basically.Recent 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 the core of the automobile is being developed from the supply through the existing fossil energy to the supply of alternative energy through electricity and hydrogen.However, the present engine can be used for some time in the future despite the replacement of the energy source.Therefore parts of an automobile engine must be inevitably used even when the energy source is changed and parts should be as durable as possible. In automobile manufacturing, it is necessary to increase the strength and to carry out the carburizing heat treatment in order to make parts compact, lightweight, and reliable in durability[1].Accordingly, heat treatment techniques for applying a high level of abrasion resistance, corrosion resistance, and fatigue resistance to automobile parts are being applied and developed. In Korea heat treatment, the carbon carburization and nitriding method are also used most basically. Such heat treatments are a heat treatment method to simultaneously impregnate carbon and nitrogen at a certain temperature, carburizing treatment in a low-vacuum anoxic atmosphere condition capable of carburizing in a short time, NH_3 and endothermic gas Oxynitriding method for producing Fe_3O_4 on the surface of a compound layer by simultaneously injecting nitriding gas and sedimentation gas, plasma nitriding method capable of controlling nitriding characteristics, low-pressure nitriding method which can obtain high hardness and abrasion resistance by using ammonia and nitrogen dioxide gas in a low-pressure vacuum and the like are and actively used applied.Steel the carburizing heat treatment is a carbon control technique, which regulates the amount of carbon by carburizing and produces martensite as a main microstructure after 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 with carbide and retained austenite tends to be cracked duringpolishing[2].

The gas carburizing heat treatment during the carburizing heat treatment is of quenching and tempering a process after in which the carbon content of the surface is increased through the heat treatment in the carburizing atmosphere in which the hydrocarbon gas is burned to in low carbon steels 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.Mechanical performance improves toughness as carbon spreads inside.Diffusion layer with good ductility by diffusion of carbon from the surface to the inside improves the mechanical performance[3,4].In this study, the experiment was used with the crankshaft sprocket and the pump drive hub specimen of the automatic transmission oil pump drive which are used in the actual car engine.Crankshaft sprocket is installed on the crankshaft of the engine, the appearance is sawtooth, in some case pulley is used instead of a sawtooth type.The function is to transfer the power of the crankshaft to other parts using a chain or belt. The test material, carbon-molybdenum alloy steel, was produced by cold forging. Also, the pump drive hub used in the automatic transmission oil pump drive supplies oil to cool the heat generated by each part of the transmission during operation. This hub is a transmission part that holds the pump shaft in one part of the oil pump drive and holds it in place.These parts can improve the power and fuel economy of the vehicle, but they can easily be destroyed, requiring high hardness and toughness on the surface of the product, as well as high abrasion resistance, fatigue strength and impact resistance.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,need an anti-carburizing or a tempering[5,6]. Therefore carburizing 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.These factors include carbon potential, carburizing material, carburization holding time and diffusion time.Therefore in this study, after the heat treatment of the gas carburization, the minimum diameter portion of the test piece was cut and the metal structure was observed using an optical microscope and a scanning electron microscope, the change in the hardness value was measured in the depth direction[7].In addition, investigation took place on the heat treatment conditions, the distribution of hardness according to the carburizing depth, the microstructural changes of the surface and internal structure required for the product when carburizing with specimen of practical product size.

2. Experimental Method

2.1. Analysis and Preparation of Specimen

The carburized test specimen materials used were chromium-molybdenum alloy steel SCM-20 and SCM-15 used for automotive parts.Composition analysis of specimens was performed by Bruker X-ray Fluorescence (WD-XRF Tiger) and as shown in Table 1.

Table1: Chemical composition of specimens

Elements	Chromium-molybdenum alloys	
	SCM-20	**SCM-15**
C	0.20	0.15
Si	0.26	0.25
Mn	0.82	0.83
P	0.015	0.014
S	0.007	0.006
Ni	0.09	0.08
Cr	1.12	1.13
Mo	0.19	0.20

The hardness and micro-structure changes of the specimens before and after the heat treatment were measured and compared. The test specimens used in this experiment were prepared with cold forging automobile oil pump drive hub and crankshaft sprocket parts. The carburizing treatment was performed to obtain the optimum hardness value required for the automobile parts. Part of the heat treated specimen was cut in the vertical direction and the test conditions were marked on the specimen. To facilitate measurement, a flat surface was obtained, followed by mounting and polishing. Wire cutting was performed to minimize changes in hardness value due to heat during cutting. Figure 1 show mounting press and mounted specimens. The mounting was carried out by placing the specimen in the center of the piston face, putting the resin powder into the mold and pressurizing with a piston. The mold temperature was 185°C, holding 3 minutes and cooling 3 minutes.In order to minimize surface scratches after mounting, rough polishing and intermediate polishing were performed in the order of # 220, # 800 and # 2000. The surface of the specimen was smoothed by using a 1μm diamond useful paste with a polishing machine (220V / 1PH) equipped with a soft pore adhered to synthetic fibers at a rotation speed of 200 rpm. And for metallographic examination using scanning electron microscope (SEM), platinum (Pt) was coated for 1 minute.

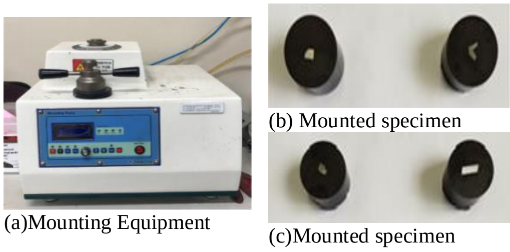


Figure 1:.Mounting equipment and mounted specimens *(a): Mounting press(Korea-tech) (b): Mounting before carburizing of drive hub and sprocket (c): Mounting after carburizing of drive hub and sprocket

2.2. Heat Treatment Condition

The pump-driven hub specimen (SCM-20) cold-rolled with chrome-molybdenum alloy steel has an outer diameter of φ124, an inner diameter of φ36 and a height of 37 mm, the crankshaft sprocket (SCM-15) has an outer diameter of 45, an inner diameter of 37 and a height of 20 mm. In order to be used as an automotive part, the effective carburizing depth of SCM-20 should be in the range of 0.8-1.2mm on the basis of micro Vickers hardness 513Hv and the effective carburizing depth of SCM-15 should be in the range of 0.2-0.45mm on the basis of micro Vickers hardness 550Hv. At a carbon potential of 0.9wt%, SCM-20 was maintained at a carburizing temperature of 930°C for 2hr while SCM-15 was maintained for 1hr in order to penetrate the surface of the specimen. Inside, 3.0 L of propane (C_3H_8) gas was injected per minute. RX-Gas maintained 350 L / min until carbon diffusion. A constant carbon potential was maintained to distribute the carburizing gas uniformly on the test specimen. During the carburization, hydrocarbons are introduced during the process and various gas reactions such as 2CO ↔ CO2, $CO+H_2 \leftrightarrow C+H_2O$, $C_3H_8 \leftrightarrow C+2CH_4$ are induced to occur simultaneously. For the carbon diffusion, the diffusion temperature was 930℃, SCM-20 was 1hr, SCM-15 was 20 min and carbon potential was 0.75wt%.In order to minimize specimen deformation and to miniaturize the structure, the specimen was quenched at 830°C for 30 minutes and then subjected to oil cooling at 130°C. Figure 2 shows the heat treatment process consisting of preheating, heating, carburizing, diffusion, cooling and oil quenching of SCM-20 and SCM-15.

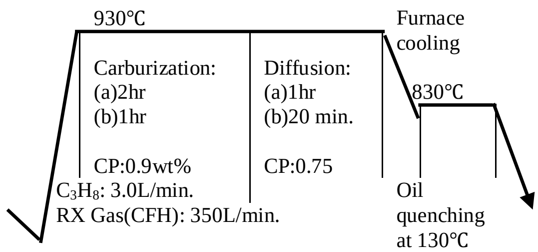


Figure2:.Gas carburizing cycle of specimens (a)SCM-20, (b) SCM-15 *CP: Carbon potential

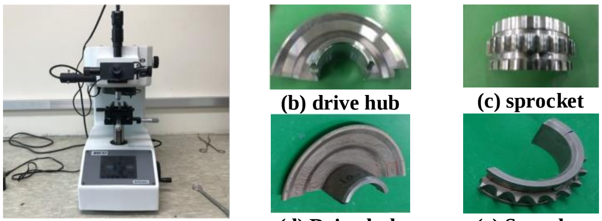
2.3. Hardness Measurement

The heat treated specimens form a hardened layer and the effective carburization thickness is determined by the hardness test.In ISO 4507, the point on the curve corresponding to 550Hv is defined as the effective carburizing thickness by the Vickers hardness test method[8].Figure 3 show carburized specimen of pimp drive hub and crankshaft sprocket.

Figure 4 show hardness tester and cutting specimen for test. The specimens of crankshaft sprocket and pump drive hubs used for automotive parts were measured and analyzed by hardening depth with a micro-Vickers hardness tester before and after carburizing. The specimens cut to a suitable size were subjected to roughing, intermediate polishing and polishing to minimize the surface roughness after resin mounting. The hardness change with depth of the carburized specimens was measured using a micro-Vickers hardness tester and hardness was measured constantly at a load of 1000 g and a load time of 10 seconds in the depth direction from the surface. The average hardness was measured 10 times at each depth. Measurements were made at different sites in the same material[3].

(a) Pump drive hub (b) Crankshaft sprocket

Figure 3: Carburized automotive parts



(a) Hardness tester **(b) drive hub** **(c) sprocket** **(d) Drive hub** **(e) Sprocket**

Figure4: Hardness tester and specimen photograph *(a): Hardness tester(MMT-X3), (b), (C): Drive hub and Sprocket of before carburizing, (d), (e): Drive hub and Sprocket of after carburizing

2.4. Structure Analysis

In general, 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 as mentioned above. Therefore, in order to analyze the microstructural changes affecting hardness of carbon and other elements in SCM-20 and SCM-15 specimens. first the specimens which did before and after the heat treatment were etched with 5% Nital solution for 8 seconds and then observed by optical microscope at 500 times and also observed with SEM(scanning electron microscope) at a constant interval of 5000 times.Figure 5 show optical microscope and scanning electron microscope for micro-structure analysis of carburized specimens.

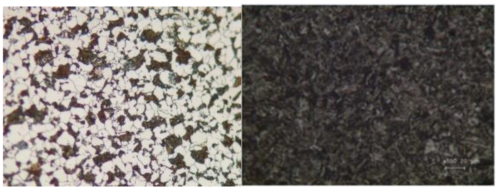
The main purpose of structure analysis was to investigate the relationship between the formation of surface abnormalities, the structure state of grain boundaries, the formation of intergranular oxide, the change of carbon content and hardness.

(a) Optical microscope (b) SEM

Figure5:.Optical microscope (OLYMPUS, JP/GX41) andSEM instruments (TESCAN, MIRA//LMH)

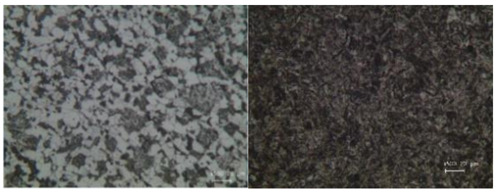
3. Results and Discussion

As shown in Figure 1, carburizing specimens of crankshaft sprockets and oil pump drive hubs for automobile parts were used.In this study, the carbon potential of 0.75-0.9wt.% was maintained when 1wt.% or more of the carbon potential was formed and a large amount of residual austenite and carbide mixed structure was formed as well as a martensite structure was formed. Therefore, there would be no over-carburizing[8].The carburization and diffusion time to reach the hardness satisfying the specifications required in the chromium alloy steel was about 1/3 of 0.2wt.% Carbon.These results are considered to be related to the carbon diffusion gradient on the surface and insideof the material[9,10]. In the case of SCM-15, even though the carburization time is short, it is considered that the higher hardness is due to the carburization and diffusion temperature as high as 930°C.Observation of pre-carburization showed that the mixture was composed of pearlite and ferrite. However, after carburizing, it was confirmed that 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 interior. Most martensite structure will be needle-like shape. The microstructures of SCM-20 and SCM-15 are shown in figure 6 and figure 7.



(a) before (b) after

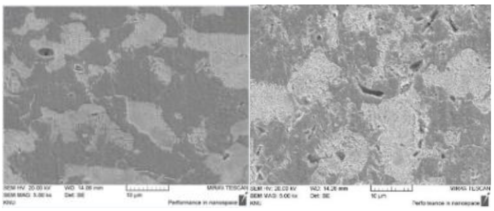
Figure 6:.Optical microscopephotograph of SCM-20(x 500) *(a): before carburizing of oil pump drive hub, (b): after carburizing of oil pump drive hub



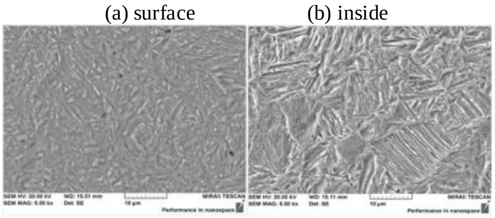
(a) before (b) after

Figure 7:.Optical microscope photograph of SCM-15(x 500) *(a): before carburizing of Crankshaft sprocket, (b): after carburizing ofCrankshaft sprocket

Figure 8 and 9 shows that the microstructures of pre-carburized SCM-20 and SCM-15 are uniformly present in pearlite and ferrite. Figure 6,7 and Figure 8,9 (c) and (d) show a trace of the structure of the oxide layer in the surface of the oxide layer, which is a cause of fatigue fracture, due to the combination of oxygen, oxygen and strong affinity of Si, Mn and Cr.



(a) surface (b) inside



(c) surface (d) inside

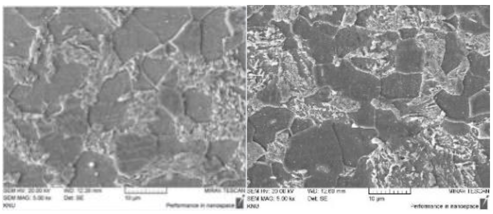
Figure 8:.SEM photographs of SCM-20 alloy steel(x 5000) *(a), (b): The before carburizing surface and inside structure, (c), (d): The after carburizing surface and inside structure

Table 2 showed the change in hardness with depth of specimen material and carburizing depth. As a result of hardness measurement, the hardness value decreased from the surface to the depth direction.

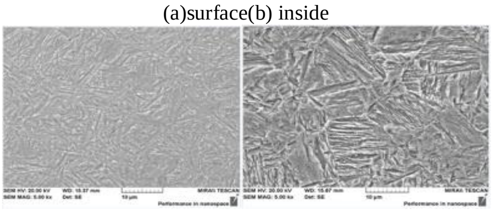
Table2: Hardness change with carburizing depth

Carburizing depth(mm)	Hardness (HV)	
	SCM-20	SCM-15
0.1	741	721
0.2	720	688
0.3	714	580
0.4	693	498
0.5	661	462
0.6	612	430
0.7	586	409
0.9	529	-
1.1	495	-
1.3	478	-
1.5	470	-

In the gas-carburizing heat treatment, the RX gas used by denaturing propane and butane with air contains a small amount of vapor and carbon dioxide gas, this gas is considered to be oxidized by oxygen bonding as carburization process[9].This causes deterioration of fatigue resistance and wear resistance. In the gas carburization method, the grain size calculation is inevitable and the Cr and Mn concentrations in the surface layer are decreased, which causes to deteriorate the surface hardenability and the incombustibility. After the heat treatment, the carburized compound was observed on the surface and the needle-like compound was mixed internally. The needle compound is judged to be a martensitic structure[10,11].



(a)surface(b) inside



(c)surface(d) inside

Figure 9:.SEM photographs of SCM-15 alloy steel(x 5000) *(a), (b): The before carburizing surface and inside structure, (c), (d): The after carburizing surface and inside structure

4. Conclusion

In this study, an experiment was conducted to find the optimum conditions for gascarburized chromium-molybdenum alloy steel used for automobile driving.As a result of analysis of structure of the chromium alloy steel before and after the carburizing, it was found that the mixture structure of pearlite and ferrite was observed. However, after carburizing, the needle-like structure tended to decrease gradually from the surface to the inside, the morphological structure is considered to be martensite structure. The internal structure shows a tendency to reduce martensite from the surface. It can be seen that this is excellent in toughness rather than hardness.The surface hardness of chromium-molybdenum alloy steel is greatly influenced by the carbon content. The surface hardness affected the amount of carburizing, and the hardness was improved as the carburizing amount increased. However, since a large amount of retained austenite is generated, proper carburizing time and diffusion will be required. The pump-driven hub required about three times more carburizing and diffusion time than the crankshaft sprocket.In order to shorten the carburization and diffusion time in terms of economy, it is considered that carbon would be stabilized by increasing the carburizing temperature and adding propane gas to RX-gas to increase the carbon potential. In the hardness measurement, 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 the value of SCM-20 test piece is the effective hardening depth at 0.96 mm and the value of SCM-15 test piece is the effective hardening depth at 0.37 mm. 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. In the future, the effect of residual austenite on surface hardness and the effect of various carbides on hardness will be analyzed through the scanning electron microscope.

References

[1] Chen FS, Wang KL. Super-carburization of low alloy steel and low carbon steel by fluidized-bed furnaces. Surface and Coatings Technology. 2000 Oct;132(1):36-44.

[2] Vetter J, Barbezat G, Crummenauer J, Avissar J. Surface treatment selections for automotive applications. Surface and Coatings Technology. 2005 Nov;200(5-6):1962-8.

[3] Ferguson BL, Li Z, Freborg AM. Modeling heat treatment of steel parts. Computational Materials Science. 2005 Nov;34(3):274-81.

[4] Krauss G. Steels: heat treatment and processing principles. ASM International, 1990,.1990:497.

[5] Ando T, Yagasaki T, Ichijo S, Sakagami K, Sumida S. Improvement of Transmission Efficiency in CVT Shifting Mechanism Using Metal Pushing V-Belt. SAE International Journal of Engines. 2015 Jun;8(3):1391-7.

[6] Sugimoto KI, Hojo T, Mizuno Y. Surface-hardened layer properties of newly developed case-hardening steel. ISIJ International. 2018 Apr;58(4):727-33.

[7] Sugimoto KI, Hojo T, Mizuno Y. Effects of fine particle peening conditions on the rotational bending fatigue strength of a vacuum-carburized transformation-induced plasticity-aided martensitic steel. Metallurgical and Materials Transactions A. 2018 May;49(5):1552-60.

[8] Davis JR, editor. Surface hardening of steels: understanding the basics. ASM international; 2002.

[9] Byun JH, Ro SH, Lee JH, Lee CH, Yang SH. Mechanical Properties of The CO 2 Free Vacuum Carburized in SCM415H. Transactions of the Korean Society of Mechanical Engineers A. 2012;36(9):971-8.

[10] Cermak J, Kral L. Effect of carbon-supersaturation upon the carbon diffusion in 9Cr–1Mo ferrite steel. Materials Letters. 2014 Feb;116:402-4.

[11] Hussiain MS, Punaykanti S, Panda RR, Mohanta D. Effect of Heat Treatment in Low Carbon Steel. International Journal of Engineering and Management Research (IJEMR). 2018;8(2):87-90.