Analysis of Surface Hardening Characteristics of Gas Carburized Chromium Alloy Steel for Automotive Constant Velocity Joint

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Abstract: The purpose of this study is to investigate the factors affecting the surface hardening characteristics of gas carburization for internal race and cage which are actually used as parts for constant velocity joints of chromium alloy steel. The specimens were made to the actual size used for the automobile parts. The carrier gas was made by adding RX gas mixed with propane and air. Propane gas and butane gas were mixed to control the carburizing gas atmosphere, and heat treatment was performed in two steps for carburization and diffusion. Hardness distributions for the carburized depths of the heat treated automotive parts were measured by micro Vickers Hardness550Hv and Rockwell hardness tester for surface and internal hardness. The test results showed that the lower carbon content, the deeper carburized layer from the surface to the inside and low surface and internal hardness values. These results show that the lower the carbon content, the shorter the carburization time. It is related diffusion time required to reach the surface and internal hardness. This may be related to the diffusion gradient of carbon on the surface and inside of the material. Acicular structure was martensite and decrease gradually from the surface to the inside. The shape of the structure changed according to the degree of carburizing. For 0.2%C chromium alloy steel, the Vickers hardness was maintained at 700Hv up to 0.7mm and the effective hardening depth hardness was 550Hv at carburizing depth of 1.4mm. For 0.15%C chromium alloy steel, the Vickers hardness value was found to be 714Hv at a carburizing depth of 0.1 mm and 550Hv at a carburizing depth of 0.7 mm.

Keywords: Carburization, Surface hardening, Chromium alloy, Inner race, Cage, Diffusion, Constant velocity joint.

I. INTRODUCTION

Recently, research for the development of artificial intelligence(AI) autonomous vehicle, which is a core technology of the 4thindustryhas been actively carried out in the world. Despite the advancement of automotive technology, automotive parts must be used inevitably, and parts must be durable. Therefore, a heat treatment technique for imparting a high level of abrasion resistance, corrosion resistance and fatigue resistance to automobile parts has been applied and developed. The carburizing method is a heat treatment method in which carbon carburization, carbon and nitrogen are simultaneously impregnated at a constant temperature. There is a surface hardening method in which ammonia gas(NH3) is added to a corrosive gas to intrude carbon and nitrogen simultaneously on the surface of the steel and then harden the surface by heat treatment. Oxy-nitride method is for producing Fe3O4 on the surface of a compound layer by simultaneously injecting nitride gas and carburizing gas. In the plasma nitride process, a nitrogen and hydrogen mixed gas of 1 to 10 torr reacts in a closed vessel to form a nitride layer excellent in abrasion resistance. High hardness and wear resistance using ammonia and nitrogen dioxide gas in a low pressure vacuum and low-pressure nitride methods are available. Vacuum heat treatment and low pressure nitrification technology are being activated recently. Heat treatment techniques should be developed to maximize productivity by minimizing deformation due to heat treatment, improving the strength of parts, and reducing costs by using minimum energy. Especially, automobile parts are subjected to surface heat treatment, and gas carburization method is popularized. The reason for this is that it is carburized deep and has high hardness. In this study, the power transmission part used in an automobile was experimented by using an inner race and a cage which are parts for a constant velocity joint(CVJ) which is assembled in a differential pinion gear and transmitted power to a wheel through an axle shaft. The inner race and cage were made by cold forging with carbon alloy steel. CVJs for automobiles consist of outer race, inner race, cage and ball. The inner race is a load-bearing automotive part that transmits torque between the transmission and the drive wheels. The cage is a key element of the constant velocity joint (CVJ), which is assembled between the outer ring and the inner ring to hold the ball in a fixed position. The inner race and cage used as parts of such a power transmission device can be easily broken, so that wear resistance, fatigue strength, impact resistance and the like must be high. Carburizing heat treatment is required to improve such mechanical properties. The carburization takes place above the austenitizing temperature and the hardening occurs during the martensitic transformation due to rapid cooling of the high carbon layer of the surface. The depth of carburizing is influenced by raw materials, carburizing material, carburizing atmosphere, carburizing temperature, carburizing time, holding time and carbon content[1,2]. In this study, two specimens with different carbon contents were carburized for the purpose of surface hardening of cage and innner race used in automotive constant velocity joints,

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and the factors influencing surface hardening characteristics were investigated. In particular, they were fabricated and analyzed to be applicable to factories.

II. EXPERIMENTAL METHOD

2-1. Specimen preparation

The test specimens used in this study were 0.2%C chromium alloy steel(SCR-20) and 0.15%C chromium alloy steel(SCR-15) as shown in Table 1, which were used for automotive parts.

Table 1.Chemical composition of specimens

Elements	Specimens(wt%)			
	SCR-20		SCR-15	
	Standard	Result	Standard	Result
C	0.18 - 0.23	0.20	0.13 - 0.18	0.15
Si	0.15 - 0.35	0.25	0.15 - 0.35	0.24
Mn	0.60 - 0.90	0.83	0.60 - 0.90	0.84
P	0.030	0.014	0.030	0.013
S	0.030	0.007	0.030	0.008
Ni	0.25	0.06	0.25	0.06
Cr	0.90 - 1.20	1.14	0.90 - 1.20	1.13

The composition of the specimens was analyzed using Brucker X-ray Fluorescence (WD-XRF Tiger). The texture change and hardness of the specimens before and after the heat treatment were compared. The test specimen to be used in the experiment was prepared with cold forged inner race and cage for use as a part of a real constant-velocity joint for automobiles. Carburizing heat treatment was performed to obtain the hardness value required by the automobile company, and a part thereof was cut in a cross section(vertical) and collected(test piece marking). In order to obtain a flat surface, it was cut and mounted in a form easy to polish and polish. Wire cutting was performed to minimize changes in hardness value due to heat during cutting. 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℃, 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, # 600, # 1200, and # 2000. Then, 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 200rpm. And for metallographic examination using SEM, platinum(Pt) was coated for 1 minute.

2.2. Heat treatment process

The inner lace cold-rolled with SCR-20 alloy steel has an outer diameter of Φ61, an inner diameter of Φ29, and a height of 30 mm. In order to be used as an automotive part, the effective carburizing depth should be in the range of 1.3-1.7mm on the basis of micro Vickers hardness 550Hv, and the surface hardness should be in the range of Rockwell hardness value HRC 58-63. The internal hardness should be in the Rockwell hardness value HRC 25-45. The carbon potential was maintained at 0.9 wt% for 10 hrs at 930℃ to penetrate carbon on the surface of the SCR-20 specimen. Inside, 2.5L of propane(C3H8) 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+H2↔C+H2O, C3H8↔C+2CH4 occur simultaneously and are carburized. The carbon potential was maintained at 0.75 wt.% For 3 hrs at 930℃ for carbon diffusion. In order to minimize specimen deformation and to miniaturize the structure, the specimen was quenched at 840℃ for 30 minutes, and then subjected to oil cooling at 130℃. The SCR-15 alloy steel cage used in this study has an outer diameter of Φ70, an inner diameter of Φ54 and a height of 34mm. In order to be used as an automobile part, the effective carburizing depth should be in the range of 0.7-1.0mm based on the micro Vickers hardness 550Hv. The surface hardness must be in the Rockwell hardness value HRC 58-63 and the internal hardness should be in the Rockwell hardness value HRC 25-45. In the first step, the temperature was maintained at 930℃ to penetrate carbon into the surface of the steel. The carburization time was maintained for 3 hours for proper carbon infiltration and the carbon potential was maintained at 0.9 wt.%. Propane (C3H8) gas was injected at a rate of 3 L / min. and RX-Gas was maintained at 350 L / min. until carbon diffusion. The carbon potential on the surface of the SCR-15 alloy steel was maintained at 0.30 wt% for 1 hr at 930℃ for carbon diffusion. SCR-15, which has a carbon content of 0.05 wt.% Lower than that of SCR-20, was quenched at 850℃ for 30 minutes, 10℃ higher than SCR-20 to minimize strain and microstructure. During the heat treatment for SCR-15, a constant carbon potential was maintained in order to uniformly distribute the carburizing gas to the test piece as in SCR-20[3]. Figure1 shows the heat treatment process consisting of carburization, diffusion and oil quenching of SCR-20 and SCR-15.

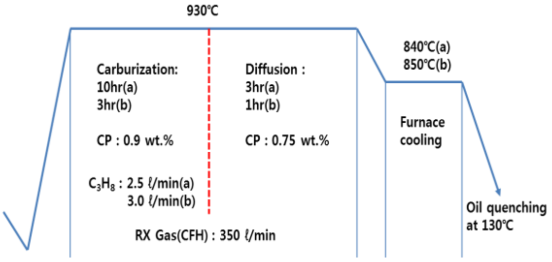


Figure1. Heat treatment cycles of specimens: (a) SCR-20, (b) SCR-15

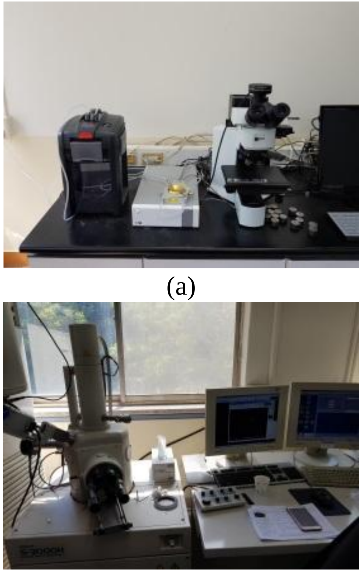
2.3. Hardness analysis

All heat treated specimens form a hardened layer and the effective carburization thickness is determined by hardness test. The point on the curve corresponding to 550Hv is defined as the effective carburizing thickness by the Vickers hardness test method.

The surface hardness of the sample before and after carburizing of the inner race and cage used for automobile parts were compared using Rockwell hardness tester and the hardening depth was analyzed by micro Vickers hardness tester. The specimens cut to a suitable size were subjected to roughing, intermediate polishing and polishing to minimize the surface roughness after resin mounting, 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.

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 structure changes affecting the hardness of carbon and other elements in this study, the specimens and post-annealed specimens were observed with a 5x Nital solution for 8 sec. We analyzed micro-structure of specimens with optical micro-scope(×500) and Scanning electron micro-scope(SEM,×2000). The main purpose of this study was to investigate the relationship between the formation of surface abnormalities, the texture state of grain boundaries, the formation of inter-granular oxide, the change of carbon content and hardness. Figure 2 is an optical microscope and SEM equipment that measures the microstructure of metal structures. In particular, the scanning electron microscope is a device for highly precise observation of the shape of the metal structure, and the mounted specimen is placed on the specimen stand. Nitrogen gas is injected inside to wait until it becomes vacuum and the electron beam is irradiated to focus. It is the equipment to analyze the metal structure by imaging the size of the signal changed by the detector with the contrast of the cathode ray tube point.



(a)

(b)

Figure 2. Optical microscope (a), SEM(b)

III. RESULTS AND DISCUSSION

Figure 3 shows the carcass specimens for the inner race and cage for constant-velocity joints for automobiles.

(a) Inner race

(b) Cage

Figure 3. Carburized inner race and cage

The hardness distribution curves of SCR-20 and SCR-15 with different carburizing depths are shown in Figure 4. The automobile parts used in the experiment are required to have wear resistance and fatigue resistance because they continuously transmit power. Therefore, it is necessary to produce high-quality, high-quality products that maintain uniform carburization and hardness values.

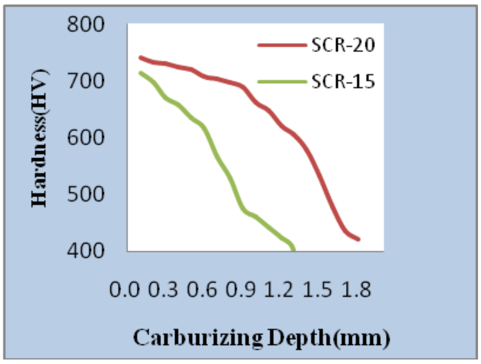


Figure 4. The carburized hardness distributions of SCR-20 and SCR-15

The SCR-20 showed the highest micro-Vickers hardness value of 741Hv at 0.1 mm surface layer with a large carburizing amount and 43.3% at 420Hv at 1.8 mm thickness. The SCR-15 showed the highest micro-vickers hardness value of 714Hv at the surface layer 0.1 mm with a large carburization amount, and it was 43.8% lower at 401Hv at the 1.3 mm thickness with small carburizing amount. The carburizing depth of SCR-20 was 0.5 mm more carburized and the effective curing depth was twice that of SCR-15.In both specimens, the hardness value decreased as the depth of carburization decreased. For SCR-20 alloy steel inner race to be used as automobile parts, effective carburization depth corresponding to micro Vickers hardness 550Hv is 1.3-1.7mm, Rockwell hardness value is HRC 58-63, internal hardness is HRC 25- 45 category. Therefore, the carbon potential was maintained at 0.9 wt.%. And the gas was carburized for 10 hrs by feeding C3H8 gas at 2.5 L / min. For carbon diffusion, RX-Gas was injected with a carbon potential at 0.75 wt.% for 3 hrs. After quenching at 840℃, oil cooling was carried out at 130℃. As a result, the surface hardness HRC 61 and the internal hardness HRC 35 were obtained. In the case of the inner race(SCR-20), the effective carburization depth of 550 Hv was maintained up to 1.54 mm. The SCR-15 alloy steel cage shall have an effective carburization depth of 0.7-1.0mm corresponding to micro Vickers hardness 550Hv, and Rockwell hardness values shall be in the HRC 58-63 surface hardness and HRC 25-45 category hardness. Therefore, the carbon potential was maintained at 0.9 wt.% And C3H8 gas was injected at 3.0 L / min. For carbon diffusion, RX-Gas was injected with 0.75 wt% carbon potential for 1 hrs. After quenching at 850℃, oil cooling at 130℃ resulted in a carburization depth of 0.83mm, surface hardness HRC 60 and internal hardness HRC 32. The Vickers hardness after carburizing was found to be 741 Hv for SCR-20 and 74 Hv for 0.1 mm surface layer with large carburizing amount and 420 Hv for 1.8 mm thickness with small carburization. The SCR-15 showed the highest micro-vickers hardness value of 714 Hv at the surface layer 0.1 mm with a large carburizing amount, carburized to 1.3 mm from the surface, and the Vickers hardness was 401 Hv. And the effective carburization depth of 550 Hv was maintained up to 0.7 mm. In this study, the carbon potential of 0.75-0.9 wt.% was retained when 1 wt.% or more of the carbon potential was formed. The martensite structure was formed by a mixed structure of a large amount of retained austenite and carbide. Therefore, there will be no excess carburization. The carburization and diffusion time to reach the hardness satisfying the specifications required in the chromium alloy steel was about 1/3 of 0.2 wt.% carbon. These results are considered to be related to the carbon diffusion gradient on the surface and inside of the material[4,5]. The shorter carburization time of SCR-15 was attributed to the higher carburization and diffusion temperature of 930℃. 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 layered structures are judged to be martensite[6,7,8]. The microstructures of SCR-20 and SCR-15 are shown in Figures 5 and 7.

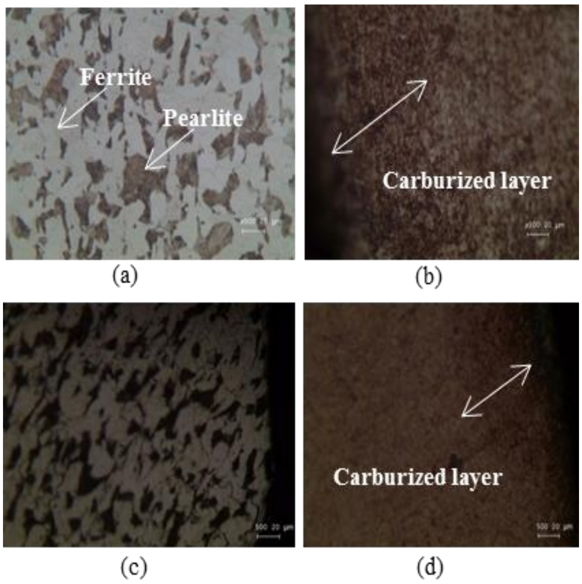
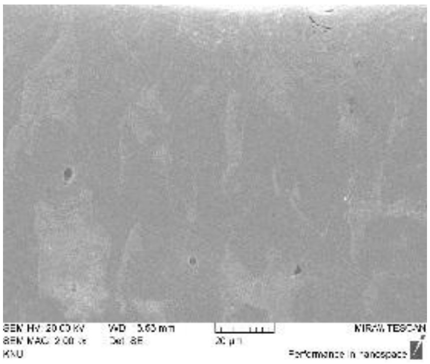


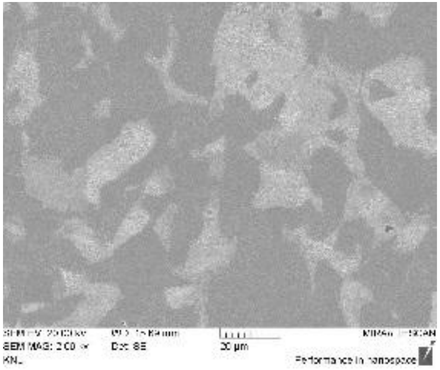
Figure 5. Optical microscope photographs(×500) [(a),(b): before and after carburizing of SCR-20, (c),(d): before and after carburizing of SCR-15]

Figure 6 is optical microscope photographs before and after carburization. It shows that the micro-structures of SCR-20 and SCR-15 are uniformly present in pearlite and ferrite. Figure 7 is photographs of SEM before and after carburization. Figure 7(a) and (c) 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. This causes deterioration of fatigue resistance and wear resistance. In the gas carburization method, grain boundary oxidation is inevitable and the surface hardenability and entanglement defect are deteriorated due to the decrease of the Cr and Mn concentrations in the surface layer. The grain boundary oxidation may deepen up to 15㎛ as the carburization time is longer. In addition, excessive carburization may result in the formation of reticular cementite. In the case of an alloy steel containing Cr, which is a carbide forming element, carbon potential is required to be lowered because it forms carbide. In the case of carbide formation inhibiting elements such as Si and Ni, the carbon potential should be adjusted high [9].Quenching is also an important step in determining the hardness and texture of the surface layer and core of the part, so it should be done at the austenite temperature. When quenching at high temperature, the retained austenite is increased. The martensite of surface carburizing layer is coarsened and the deformation amount becomes large. However, when quenching at too low a temperature, the core hardness is not stabilized and the deformation may become large[10,11]. In order to shorten the carburization time and diffusion time for high economical efficiency, it is necessary to stabilize carbon by increasing the carburizing temperature and raising the carbon potential by adding propane gas to RX-gas. According to the first law of Fick, when the difference between the carbon potential of the gas and the carbon amount of the steel is
large,

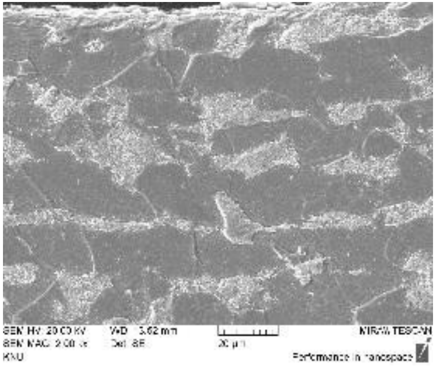
the amount of carbon diffusion becomes large, and the carburizing process time is shortened. The reason why the Vickers hardness value of SCR-15 carbon alloy steel is lower than SCR-20 carbon alloy steel is considered to be closely related to the carbon composition of SCR-15 carbon alloy steel specimen. However, since a large amount of retained austenite is generated, proper carburizing time and spreading will be required.



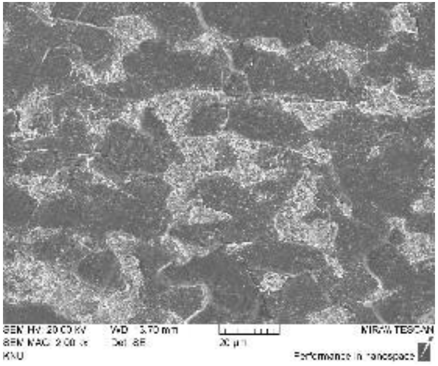
(a) Surface



(b) Middle

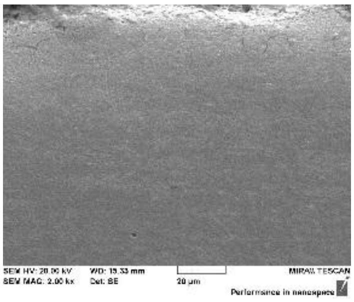


(c) Surface

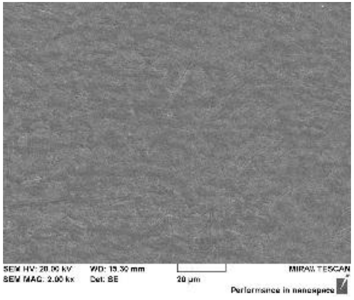


(d) Middle

Figure 6. SEM photographs(×2000) [(a),(b) : before carburizing of SCR-20, (c),(d): before carburizing of SCR-15]



(a) Surface



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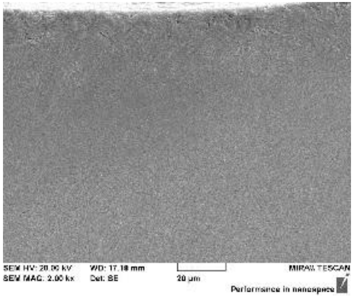
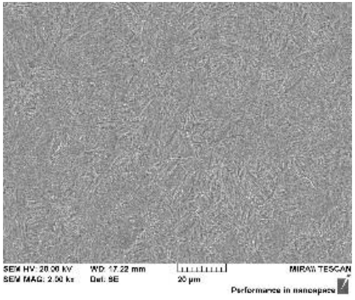


(c) Surface



(d) Middle

Figure 7. SEM photographs (×2000) [(a),(b) : after carburizing of SCR-20, (c),(d) : after carburizing of SCR-15]

IV. CONCLUSION

In this study, we investigated the factors affecting on the hardness of carburized chromium alloy steel. The carburized structure of chromium alloy steel was analyzed before and after carburizing, and the structure of the mixture of pearlite and ferrite was observed. 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 surface hardness of chromium alloy steel is greatly influenced by the carbon content. The higher carburizing amount, the higher hardness in the marten site mixed structure. In order to determine the carburizing temperature, it is necessary to consider the growth and deformation of the crystal grains, the economic efficiency, and determine the carburizing time by the depth of the carburizing layer. Quenching is also an important step in determining the hardness and texture of the surface layer. If the heat treatment time such as carburization and diffusion is prolonged, the cause of the increase in the production cost of the heat treatment industry is provided. Therefore, it is necessary to be able to generate the carburization thickness having the optimum strength in the shortest time in terms of economy. The time required for carburization and diffusion needs to be optimized depending on the application of the automobile parts, so we will study related characteristics such as the durability of the actual automobile parts in the future. Since the results of this study were produced and analyzed in a real size, they could be applied directly to the factory.

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