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# Effects of Nb-Addition on Carburizing Treatment for Low Carbon Steel

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**Carburization is widely applied to low carbon steel to increase its surface hardness and wear capability. In recent years, it has been feasible with technology to reduce the time of the carburizing process by means of increasing the carburizing temperature for the purposes of energy saving and high efficiency. However, grain coarsening accompanying the elevated-temperature carburizing process deteriorates the final mechanical properties and makes the dimensional accuracy worse induced by the heat treatment distortion. Hence, Niobium (Nb) micro-alloying was developed to prevent grain coarsening during elevated-temperature carburizing. In this study, the effects of Nb-additions on SAE 1022 carbon steel in a gas carburizing process would be analyzed to compare the carburizing properties with traditional SAE 1022. In elevated-temperature carburizing, the Nb-modified SAE 1022 steel showed a faster carbon atom diffusion and deeper case depth than the conventional one. Finally, an optimization of the gas carburizing process for Nb-modified SAE 1020 steel would be developed to improve productivity and cost saving.**

**Keywords: SAE 1022, Niobium micro-alloying, Gas carburizing process.**

## 1. INTRODUCTION

Carburizing is a heat treatment which is essentially the addition of carbon to the surface of low-carbon steel by exposure to an appropriate atmosphere at temperatures in the austenite phase field. Austenite, exists generally between 850°C and 950°C, which is the stable crystal structure with a high solubility for carbon. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core[(1)]. Case depth of carburized steel is a function of carburizing time and the available carbon potential at the surface[(2)]. When prolonged carburizing times are used for deep case depths, or a high carbon potential is adapted to produce a high surface-carbon content, which may result in excessive retained austenite or free carbides. Both two microstructural elements have adverse effects on the distribution of residual stress in the case hardened part. Consequently, a high carbon potential at a higher carburizing temperature may be suitable for shorter carburizing times but not for prolonged carburizing.

Manufacturers have long been concerned about trying to use higher carburizing temperatures for producing case hardened components. Since carbon diffuses more quickly into the surface layer at higher temperatures, the required process time can be shortened to make the case hardening process more cost efficient. It was reported that at the carburizing temperature of 950°C, a carburization depth of 1.0mm is expected after five hours. When the carburizing temperature was raised to 1050°C, the process for a carburization depth of 1.0 mm only required two hours representing a time saving of 60 percent[(3)]. There was an important issue when trying to achieve this potential cost saving. Grain growth usually occurs at this higher temperature range when conventional material concepts are used. However, coarse grain impairs the functional characteristics of the components. In order to optimize end-use performance, an austenite grain size of ASTM 5 or finer is nowadays expected in most cases[(4)]. This requirement means that fine-grained steels with appropriate fine-grain stability have to be used[(5)].

The precipitates of carbide, nitride and carbide-nitride can restrain the migrations of grain boundary in elevated temperature in carbon steel. In recent years, niobium micro-alloying has been developed to prevent grain coarsening during elevated-temperature carburizing. In this study, the Nb-modified SAE 1022AK (1022M1) was developed to improve carburizing performance for replacing conventional SAE 1022AK. The relationships between carburizing temperature and heat treatment time in a gas carburizing process would be analyzed for both materials. At an elevated carburizing temperature, 1022M1 steel showed faster carbon atom diffusion and a deeper case depth than that of 1022AK. Finally, an optimization of the gas carburizing process for a small screw sample of 1022M1 steel would be tested to prove the improvement of productivity.

## 2. EXPERIMENTAL METHOD

### *2.1 Materials*

Low carbon steel Nb-modified 1022M1 and SAE 1022AK were collected from hot-rolled coils individually. Their chemical compositions were tested by spectroscopic analysis according to ASTM E 415-99a which is shown in Table 1. The test specimens for carburizing experiments were prepared from the bar materials whose dimensions are given as a diameter of 5.5 mm and a length of 30 mm.

### *2.2 Carburization temperature*

For more efficient case carburizing, the carburizing steel would be heat treated at the temperature upon Ac3. In this work, Ac3 temperatures for 1022M1 and 1022AK were measured by the thermal dilatometer. The bar specimens were machined to a diameter of 4 mm and a length of 10 mm. The specimens were heated to 1000°C for about 120 seconds in a vacuum and then quickly cooled down at a rate of 100°C per second. The changes of length and temperature were recorded and plotted in Fig.1. The Ac3 temperatures of both 1022M1 and 1022AK were between 833°C and 834°C. In general, the austenitizing temperature would be set at a temperature higher than that of the Ac3 temperature of between 30°C and 50°C for homogeneity. So the austenitizing temperature of both materials must be at 864°C for the least extent. Meanwhile, the martensite transformation temperatures of SAE 1022M1 and 1022AK were 430°C and 420°C respectively were individually measured and shown in Fig.1.

The austenitizing temperature could also be evaluated by JMatpro simulation. Meanwhile, the Continuous Cooling Transformation (CCT) diagram could be calculated by means of bring the compositions and grain size of both materials into JMatpro. The austenitizing temperatures of both materials were the same at about 876°C, similar to the results obtained by the thermal dilatometer. So the carburizing temperature for both materials were setup at above 880°C. Figure 2 shows the CCT diagram of SAE 1022M1 and 1022AK. The only difference is that the curves for SAE 1022AK have shifted a little bit towards the right. This indicates that SAE 1022AK has a better hardenability than SAE 1022M1.

**Table 1** Compositions of SAE 1022M1 and SAE 1022AK

| Element | C | Si | Mn | P | S | Cr | Ni | Al | N | Nb | Ti | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1022M1 | 0.19 | 0.06 | 0.83 | 0.013 | 0.007 | 0.01 | 0.01 | 0.046 | 0.005 | 0.031 | 0.001 | balance |
| 1022AK | 0.19 | 0.06 | 0.78 | 0.016 | 0.006 | 0.02 | 0.01 | 0.041 | 0.005 | 0 | 0.002 | balance |

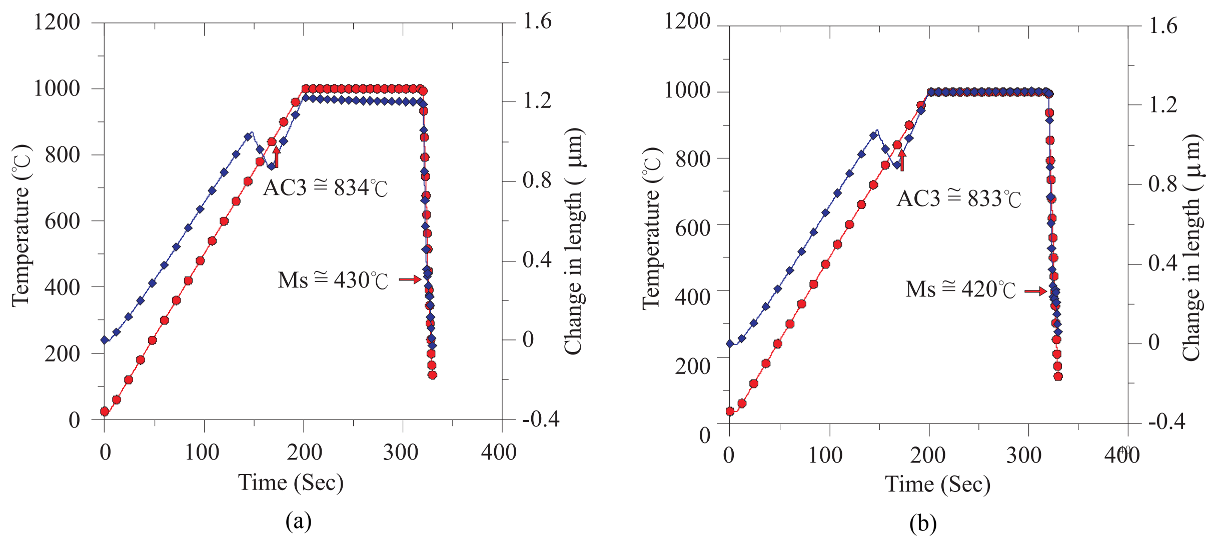
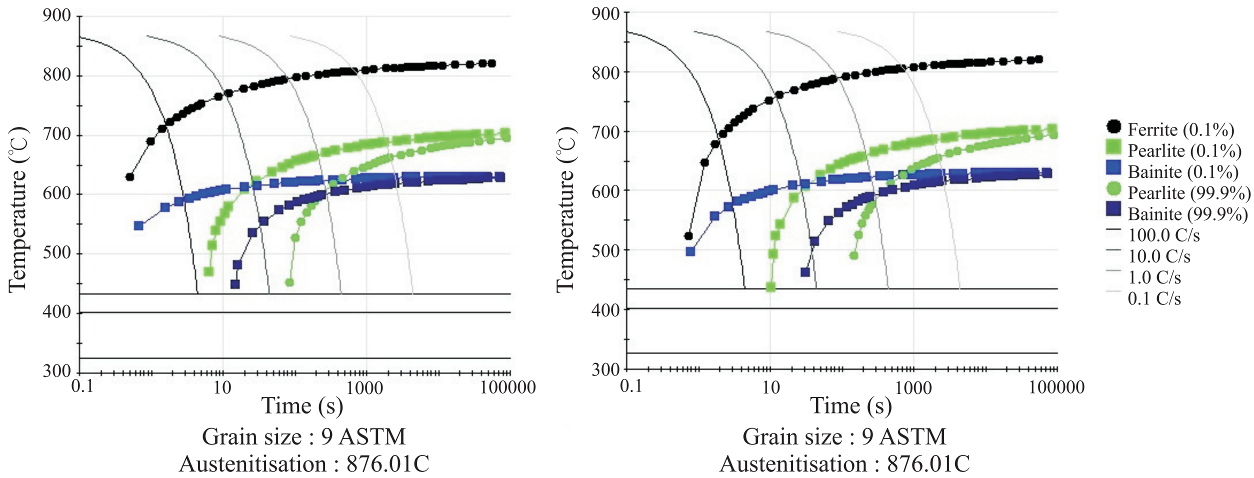



**Fig.1.** The relationship of length and temperature for (a) 1022M1 and (b) 1022AK.




(a) (b)

**Fig.2.** The CCT diagrams of (a) 1022M1 and (b) 1022AK

### *2.3 Gas carburizing process*

The fastener has always been gas-carburized by a continuous furnace in the manufacturing industry as shown in Fig.3. The gas carburizing process consists of preheat (I), carburizing (II, III), diffusing (IV, V), and quenching (VI). The work pieces go through these heating processes and then drop into a pool of quenching oil, they then go to the tempering furnace. In this work, the carburizing process was designed according to the continuous furnace. The carbon potential and the heating temperature in every process were listed in Table 2. In order to compare the carburizing effects between both materials, all parameters were fixed except for the carbon potential and the carburizing temperature in zones II and III. All carburizing specimens were subjected to 880°C, 900°C, 920°C, 950°C, 980°C respectively during the II and III process, and finally tempered at 200°C for 60 minutes. The Carburizing temperatures described in this study are aimed at the heating temperature of the II and III process and the heat treatment time is meant for the duration of all the processes.

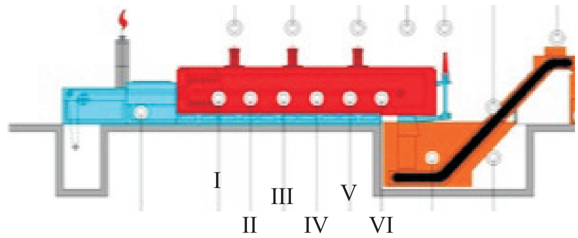



**Fig.3.** Schematic drawing that illustrates the gas-carburizing process.

## 3. RESULTS AND DISCUSSION

### *3.1 900°C carburizing temperature*

The micro hardness was measured with a 200g load HV to prove the carburizing effect in comparison between two materials. The surface for the micro hardness measurement was then cross-section cut at the midpoint of the carburizing bar's length. The distribution of hardness for both materials carburized at 900°C for 1 hour and then 2 hours were plotted as shown in Fig.4. For 1 hour-carburizing, the surface hardness and case depth at 550 HV for 1022M1 is lower than 1022AK as shown in Fig.4(a). Extending carburizing time to 2 hours, the case depth for the two materials increases with treatment time increasing. The surface hardness for 1022AK carburized for 2 hours is about 750 HV and similar to the 1 hour result. But the surface hardness for 1022M1 increases by about 100 HV with treatment time increasing. Figure 5 shows the microstructure in the carburizing layer of 1022M1 and 1022AK carburized at 900°C for 1 hour. The matrixes for 1022M1 and 1022AK are tempered martensite. But

**Table 2** The heating process of carburization for 1022M1 and 1022AK

| Process | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Carbon potential (%) | 0.8 | 1.0~1.2 | 1.0~1.2 | 0.95 | 0.95 | 0.8 |
| Temperature (°C) | 900 | 900~980 | 900~980 | 900 | 880 | 830 |

there are a few bainite structures and carbides spread in the grain boundary of 1022M1. That is why the surface hardness for 1022M1 is lower than 1022AK.

### *3.2 920°C carburizing temperature*

The variations of micro hardness with depth in 1022M1 and 1022AK carburized at 920°C for 1 hour and then 4 hours are shown in Fig.6. The values of the surface hardness for both materials are within the same range of between 760 HV and 780 HV due to the same

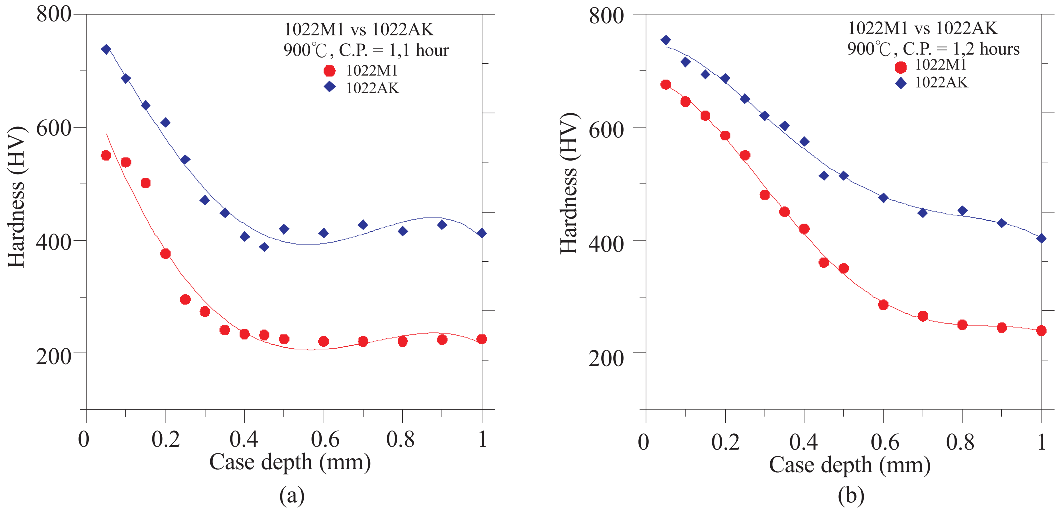



**Fig.4.** Variation of hardness with depth carburizied at 900°C for (a) 1 hour and (b) 2 hours.

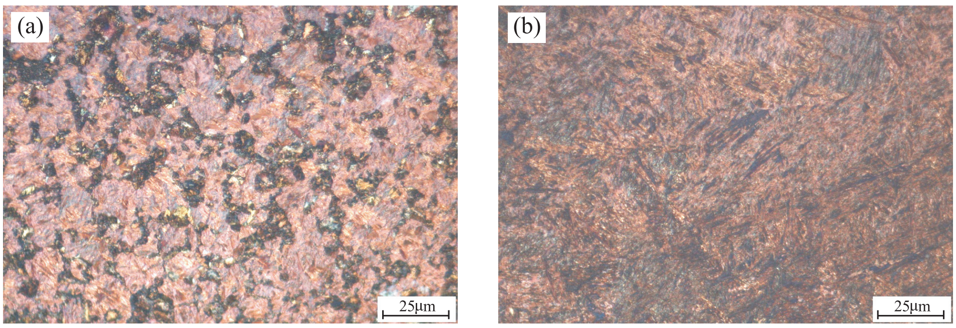



**Fig.5.** Microstructure in the carburizing layer of (a) 1022M1 and (b) 1022AK carburized at 900°C for 1 hour.

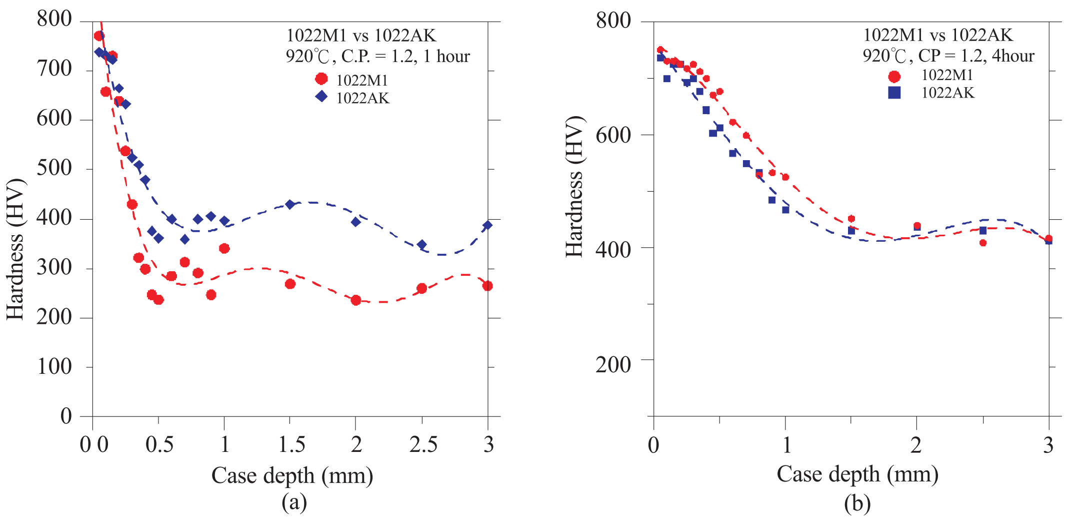



**Fig.6**. Variation of hardness with depth carburizied at 920°C for (a) 1 hour and (b) 4 hours.

carburizing temperature. The case depths for 1022M1 carburized at 920°C for 1 hour is a little bit lower than 1022AK, but there is an opposite characteristics on the case depth for 4 hours. At a 920°C carburizing process, the grain of 1022AK could grow with longer heat treatment time. That causes the effect paths through the grain boundary for the carbon atoms diffusing to be decreased in 1022AK. However, the additions of Nb in 1022M1 restrain the behavior of grain growth in austenite to keep more boundaries of fine grains for carbon atoms diffusing. Otherwise, the values of core hardness for 1022M1 are the same as 1022AK for 4 hours-carburizing, but lower than 1022AK for a 1 hour process. The ferrite precipitated in the grain boundary in 1022M1 carburized for 1 hour is observed in Fig.7. It could be imputed that the hardenability of 1022M1 is lower than 1022AK as described in Fig.2.

### *3.3 950°C and 980°C carburizing temperatures*

The variations of hardness with depth in both 1022M1 and 1022AK carburized at 950°C and 980°C for 1 hour are as shown in Fig.8. The values of case depth and core hardness for 1022M1 are higher than 1022AK at both elevated temperatures. The diffusion of carbon atoms in 1022AK seems to slow down due to austenite grain growth. At a higher austenitizing temperature, the few coarse precipitates of aluminum nitride existed in aluminum killed steel could not restrain the occurrence of recrystallization in austenite and grain growth. Figure 9 shows the variation of austenite grain size with carburizing temperature for aluminum killed steel. The temperature of grain growth occurred in SAE 1015 was at about 920°C. So 1022AK has less carburizing performance when carburized at 950°C for 1 hour and at 920°C for 4 hours. The reduction of the effect diffusing path in the coarse grain resulted in the inefficiency of gas-metal reaction and the diffusion of carbon atoms. The microstructure in the carburizing layer of 1022M1 and 1022AK carburized at 950°C for 1 hour are as shown in Fig.10. The number of carbides precipitated during the 950°C carburizing process is less than the 900°C carburizing process in comparison with Fig.5(a). On the other hand, the coarse martensite structure is observed in Fig.10(b). The carburizing process at over 920°C may help the austenite grain growth in 1022AK.

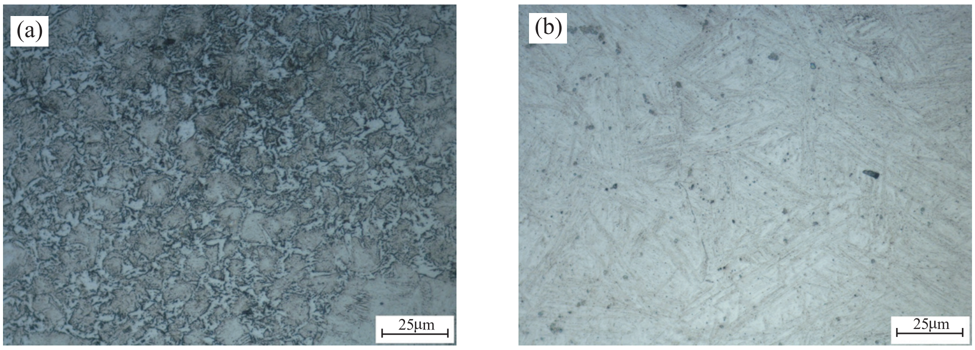



**Fig.7.** Microstructure in the core of (a) 1022M1 and (b) 1022AK carburized at 920°C for 1 hour.

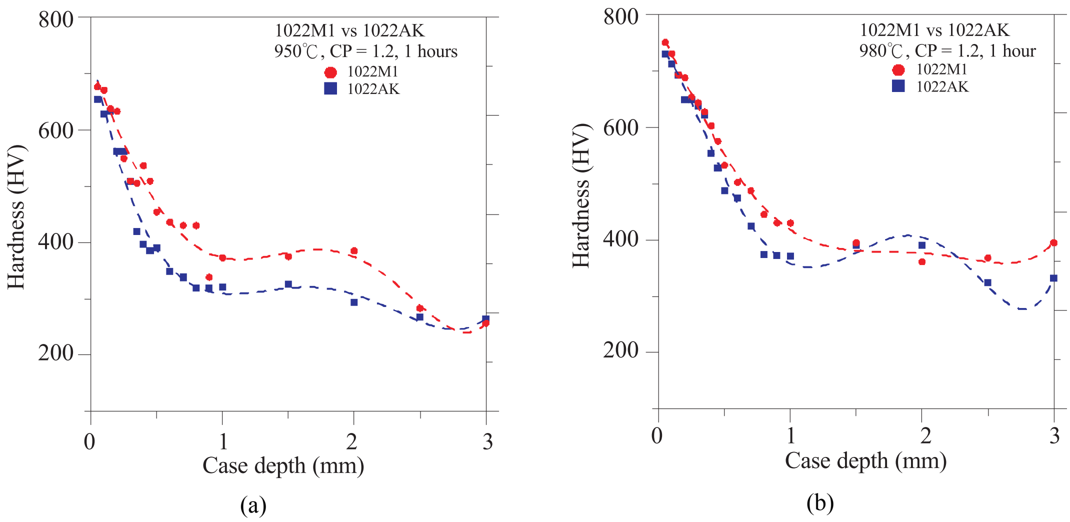



**Fig.8.** Variations of micro hardness with depth in SAE 1022 carburized at (a) 950°C and (b) 980°C for 1 hour.

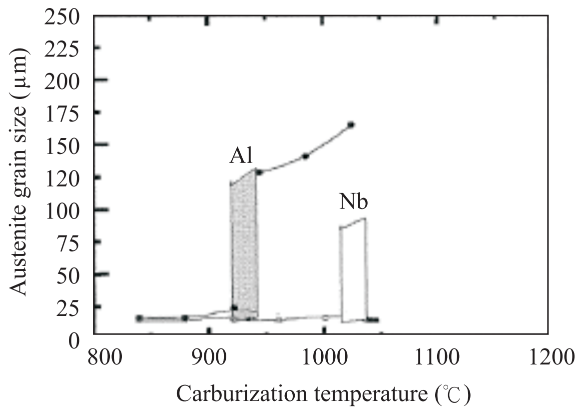



**Fig.9.** Variations of austenite grain size with carburizing temperature in SAE 1015 steel(6).

### *3.4 Carburizing within 50 minutes*

As the results presented earlier, Nb additions in 1022M1 can help avoid excessive austenite grain coarsening during elevated carburizing temperatures. So 1022M1 can be carburized quickly by means of raising the carburizing temperature. In general, the small fastener work pieces are carburized within 1 hour during the manufacturing process. So a carburizing process of 50 minutes on 1022M1 and 1022AK were performed to verify the results mentioned before. The variations of hardness with case depth in 1022M1 carburized at different temperatures for 50 minutes were plotted in Fig.11(a). The values of both the surface hardness and effective case depth (550 HV) increase with the carburizing temperature increase. However, the values of core hardness can be sorted by carburizing temperature grade. When 1022M1 carburized at a temperature greater than 950°C, the values of core hardness are close to 400 HV. On the contrary, the values of core hardness are less than 250 HV for the carburizing temperature of 920°C or less.

The comparisons of effective case depth (550 HV) with carburizing temperatures between 1022M1 and 1022AK carburized are shown in Fig.11(b). Carburizing treatment at 920°C or below, the carburizing efficiency for 1022M1 is lower than 1022AK. But at over 920°C, a deeper case depth was measured in 1022M1

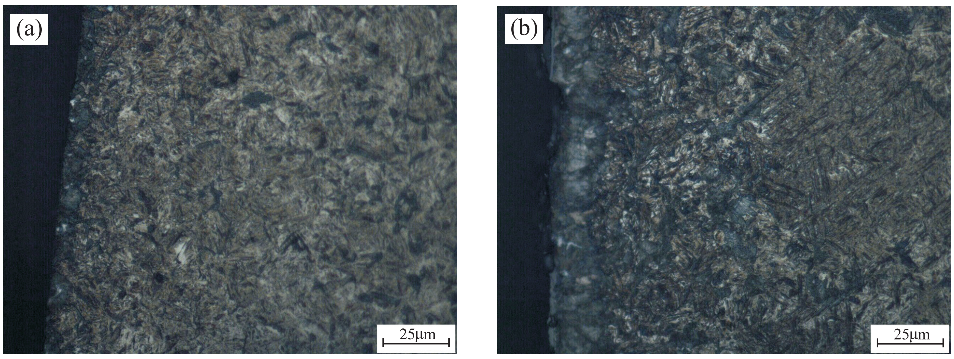



**Fig.10.** Microstructure in the carburizing layer of (a) 1022M1 and (b) 1022AK carburized at 950°C for 1 hour.

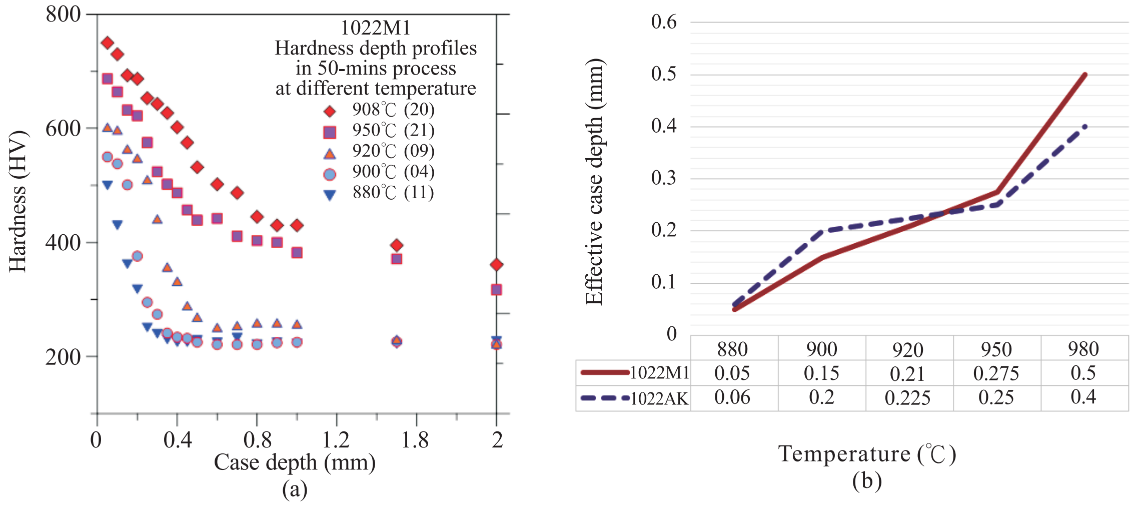



**Fig.11.** Variations of micro hardness with depth in 1022M1 carburized at different carburizing temperature for 50 minutes.

to that of 1022AK. That is to say, if the desired effective case depth was supposed to be 0.2 mm, the carburizing treatment time would be less than 50 minutes in 1022M1 when carburized at 950°C.

## 4. CONCLUSIONS

Niobium precipitates can be used in 1022M1 carburizing steels to control the austenite grain size at elevated carburizing temperatures. Thus the carburizing time to achieve the specified carburizing depth can be significantly reduced resulting in an energy saving. In this work, the values of both case depth and core hardness in 1022M1 are better than 1022AK, when carburized at 950°C or higher. The advantage of carburizing properties in 1022M1 derives from the anti-coarse grain growth of Nb-additions. However, the values of both surface and core hardness in 1022M1 are lower than that of 1022AK when carburized at 920°C or below within a 2 hour-process. So the optimization carburizing treatment for 1022M1 is performed at the elevated temperature of 950°C or above. The desired value of the surface hardness can be controlled by adjusting the carbon potential during carburizing. By the way, the mechanical properties and fatigue resistance for 1022M1 are under study.

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