Effects of Niobium Additions on the Structure, Depth, and Austenite Grain Size of the Case of Carburized 0.07% C Steels

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Carbon (0.07%) steel samples containing about 0.04% Nb singly and in combination with nitrogen were carburized in a natural Titas gas atmosphere at a temperature of 1223 K (950 °C) and a pressure of about 0.10 MPa for 1/2 to 4 h, followed by slow cooling in the furnace. Their microstructures were studied by optical microscopy. The austenite grain size of the case and the case depths were determined on baseline samples of low-carbon steels and also on niobium and (Nb + N) microalloyed steel samples. It was found that, when compared to the baseline steel, niobium alone or in combination with nitrogen decreased the thickness of cementite network near the surface of the carburized case of the steels. However, niobium in combination with nitrogen was more effective than niobium in reducing the thickness of cementite network. Niobium with or without nitrogen inhibited the formation of Widmanstätten cementite plates at grain boundaries and within the grains near the surface in the hypereutectoid zone of the case.

It was also revealed that, when compared to the baseline steel, niobium decreased the case depth of the carburized steels, but that niobium with nitrogen is more effective than niobium alone in reducing the case depth. Niobium as niobium carbide (NbC) and niobium in the presence of nitrogen as niobium carbonitride, [Nb(C,N)] particles refined the austenite grain size of the carburized case, but Nb(C,N) was more effective than NbC in inhibiting austenite grain growth.

1. Introduction

HEAVY-DUTY applications such as drive shafts, transmission gears, and bus and truck gears, demand an increased hardness and wear-resistant surface with a suitable tough core. Moreover, advanced aircraft and helicopter applications require high-duty transmission gear materials. These gear materials must be able to retain their hardness and strength at elevated temperatures up to about 588 K (315 °C). On the other hand, improved fuel efficiency for some high-consumption vehicles may be achieved by reducing the weight of the vehicle components. For this, the growing trend is to couple the engine with smaller transmissions. Consequently, higher stresses are imposed on the transmissions. Such parts made of plain carbon steel do not retain their strength and hardness at elevated temperature. Therefore, parts used for heavy-duty and high-temperature applications usually are made of low-carbon low-alloy steels. To achieve the required properties, the parts are then carburized, followed by hardening.

The carburizing behavior of plain carbon steels is well established. A number of studies (Ref 1-7) have already been made on the carburizing behavior of low-alloy steels containing nickel, chromium, molybdenum, vanadium, and so forth. Very little is known about the carburizing behavior of niobium microalloyed steel. The present work has been undertaken to study the effects of the addition of about 0.04% Nb separately and in combination with about 0.02% N on the structure, depth, and austenite grain size of the case of carburized low-carbon steels.

2. Experimental Procedure

2.1 Materials, Specimen Preparation, and Carburization

Three different steels with the compositions given in Table 1 were used in this work. Of the three, steel 1 is the base steel with which the carburizing behavior of the other two steels containing niobium alone or in combination with nitrogen was compared. Locally available natural Titas gas, a common carburizing medium (Ref 8) with an input composition of 97.2% methane, 1.8% ethane, 0.3% propane, 0.2% butane and higher hydrocarbons, and 0.3% nitrogen (Ref 9), was used for carburization. From the stock materials, specimens about 10 by 10 by 8 mm in size were prepared and carburized in a sealed chamber of a gas-fired gas-carburizing furnace with an automatic control system. The details of the furnace, control system, and carburizing procedure are available elsewhere (Ref 10).

To study the effect of gas flow rate on case depth, the carburization was carried out at three different flow rates—0.17, 0.28, and 0.34 m³/h (6, 10, and 12 ft³/h) at a constant temperature of 1223 K (950 °C) with approximately 0.10 MPa (15 psia) gas pressure for 1 h. For each case, a constant flow rate was maintained using a flowmeter.

After the predetermined time, the firing was stopped and the specimens allowed to cool in the chamber to room temperature. The gas flow through the carburizing chamber was maintained during the cooling period until the temperature in the chamber reached about 773 K (500 °C). This was done as a measure of...
precaution to prevent any possible oxidation due to infiltration of air. Following the same procedure, another batch of steel samples was carburized at the identical conditions with a gas flow rate of 0.34 m$^3$/h (12 ft$^3$/h) for five different time periods: 1/2, 1, 2, 3, and 4 h.

### 2.2 Optical Microscopy and Measurement of Case Depth

The carburized and furnace-cooled specimens were cut into two pieces at right angles to reveal the section orthogonal to the treated surface. One piece of each specimen was then mounted, polished by standard techniques, and etched in 2% nital. The microstructures of these specimens were examined by optical microscope.

Case depth is usually specified as the depth below the surface of a carburized part at which a defined value of some property occurs. The depth of carbon penetration from the surface toward the interior containing carbon up to 0.4 wt% of the carburized specimens was considered to be an effective case depth (Ref 11). The effective case depth was measured linearly from the microstructures of these specimens by using a micrometer eyepiece fitted to an optical microscope (Shimadzu Model No. 3261, Shimadzu Scientific Instruments, Inc., Columbia, MD).

### 2.3 Determination of Austenite Grain Size of the Carburized Case

The three important zones of the carburized case are the hypereutectoid zone, the eutectoid zone, and the proeutectoid zone. It is very difficult to reveal the grain boundaries of eutectoid steels. The grain size of the case thus was obtained by taking the average grain size of the hypereutectoid and proeutectoid zones. For austenite grain size measurement, the mean linear intercept method (Ref 12) was employed. A total of about 300 to 400 intercepts were counted for each specimen.

## 3. Experimental Results

### 3.1 Optical Microscopy

The structures in the case and core of specimens of steels 1 to 3 carburized for different time periods and cooled slowly in the furnace were studied by optical microscope. The optical micrographs of specimens carburized for 1 and 4 h are presented in Fig. 1 and 2, respectively.

In these carburized specimens, three different zones were distinguished:

- **Hypereutectoid zone**, consisting of pearlite and cementite network
- **Eutectoid zone**, consisting of only lamellar pearlite
- **Hypoeutectoid zone**, consisting of ferrite and pearlite

The cementite networks of steel 1 were found to be thicker than those of steels 2 and 3. Steel 2 showed thinner cementite networks than steel 1 but slightly thicker ones than steel 3 for all the carburizing periods. In all three steels, a gradual thickening tendency of the cementite networks with increasing carburizing time was observed. In each case, the depth of hypereutectoid zone in steel 3 was found to be lower than those of steels 1 and 2.

Steel 1 carburized for 4 h showed some Widmanstatten cementite plates nucleated at the grain boundary and within the grain (Fig. 2a) in the hypereutectoid zone near the surface. No Widmanstatten cementite plates were found in the structures of steels 2 and 3 for any carburizing period.

### 3.2 Case Depth

The variation of case depth with gas flow rate for steels 1 to 3 carburized for 1 h and cooled slowly in the furnace is shown in Table 2. It is clear that the effective case depth for all the steels increases with increasing gas flow rate.

The effective case depth of steels 1 to 3 carburized for 1/2, 1, 2, 3, and 4 h at a gas flow rate of 0.34 m$^3$/h (12 ft$^3$/h) and cooled slowly in the furnace are shown in Table 3 and plotted in Fig. 3 as a function of carburizing time. It is also evident that under identical carburizing conditions, steel 1 produced higher case depth than steels 2 and 3, and that steel 2 produced somewhat higher case depth than steel 3.

### 3.3 Prior Austenite Grain Size

Prior austenite grain size is important in that it controls the structures of both the case and the core of a carburized steel. Therefore, the grain size in the case of carburized and slowly cooled specimens of steels 1 to 3 was measured for different carburizing times. The data thus obtained are listed in Table 4 and plotted in Fig. 4 as a function of carburizing time.

It is evident that the prior austenite grain size of steels 1 to 3 increases with increasing carburizing time. It is also clear that plain carbon steel 1 produced the coarsest grain size, whereas steel 3 produced the finest grain size of all the steels and steel 2 produced a coarser grain size than steel 3. Figure 4 shows that the prior austenite grain sizes of steels 2 and 3 are very close to each other for lower carburizing periods. However, the difference between them increases with the increasing carburizing time. Figure 2 shows the grain size of the case of steels 1 to 3 carburized for 4 h and cooled slowly in the furnace.

### Table 1 Compositions of steels

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<th>Nb</th>
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