

Photo. 5.
Microstructures observed in Fe-0.99%C alloy treated isothermally under high pressure

- (a) Proeutectoid carbide (PC) and pearlite (P); 29 kbar, 650°C x 2 min
(b), (c) Proeutectoid carbide in martensite matrix (M+PC) and coarse proeutectoid carbide in ferrite matrix (F+C); 38.5 kbar, 650°C x 1 hr

in Fig. 4, the area A+C spreads wider with an increase of pressure.

Photographs 5, 6, 7, and 8 show the microstructure of the materials transformed isothermally at high pressures. Photograph 5 shows the microstructures of A-9 alloy appeared in a temperature range higher than the nose. Photograph 5 (a) shows a microstructure obtained at 650°C and 29 kbar, and it is similar to a generally observable structure in a hypereutectoid steel at 1 atm. When the pressure was increased to 38.5 kbar, the alloy showed a entirely different structure as shown in Photos. 5 (b) and (c). Namely, although the specimen was thought to be in the midst of the transformation in this case, the observed structure was consisted of ferrite (white) and martensite (dark) with fine carbide particles precipitated on the whole surface, instead of the eutectoid products such as pearlite. Of course, the martensite in this structure was the one which had been transformed from the untransformed austenite after the isothermal treatment. This result suggests that these ferrite and carbide were separately transformed or precipitated from austenite and then grown, and did not pass through the eutectoid reaction. As the quantity of

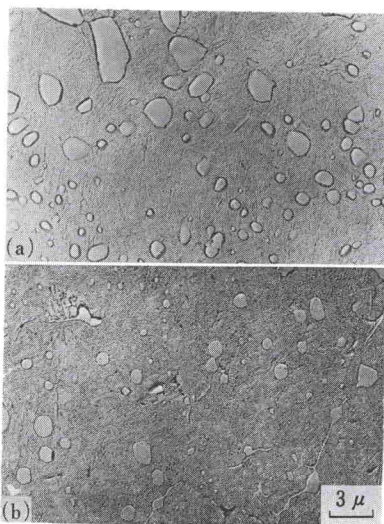


Photo. 6.
Spherical carbide in martensite matrix observed in Fe-0.99%C alloy (a) and 1.11%C steel (b) treated isothermally under high pressure
(a) 38.5 kbar, 450°C x 2 min
(b) 29 kbar, 550°C x 2 min

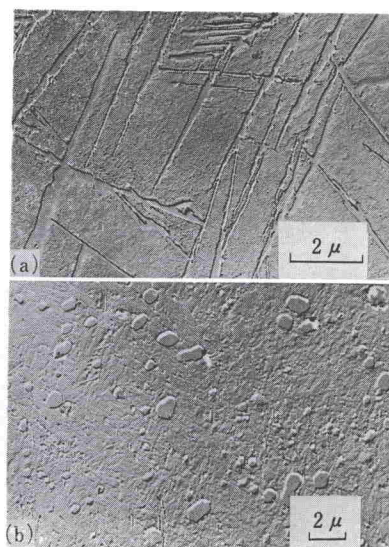


Photo. 7.
Electron micrographs of carbide in 1.11%C steel treated isothermally for 20 min at 500°C and 38.5 kbar after austenitized at 1050°C (a) and 950°C (b)

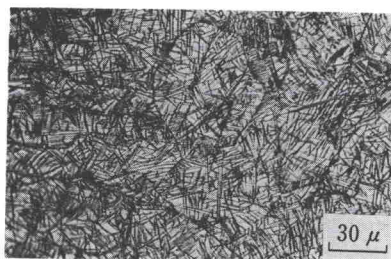


Photo. 8. Acicular carbide observed in 1.11%C steel treated isothermally for 30 min at 500°C and 38.5 kbar

the precipitated proeutectoid carbide would increase with an increase of pressure, so that the carbon content in austenite after the precipitation must be become lower. Thus the "diluted" carbon in austenite would be precipitated at the proeutectoid carbide existed already before or in the midst of the $\gamma \rightarrow \alpha$ reaction.

Although the structure similar to the one in Photos. 5 (b) or (c) is scarcely observed on the specimen heat treated at atmospheric pressure except in the case of spheroidizing annealing, it is not difficult to obtain such a structure in high pressure treatment. The reason for this is thought to be that the driving force for promoting pearlitic transformation at this temperature would be relatively decreased with the drop of A_1 temperature caused by an increase of pressure.

On the other hand, the shape of the carbide particles observed in SK3 steel changed from spherical to acicular depending on the applied pressure and temperature. Namely, the carbide precipitated at 29 kbar was always identical in its shape to the one obtained in the A-9 alloy regardless of its austenitized or transformed temperature as shown in Photo. 6, but when

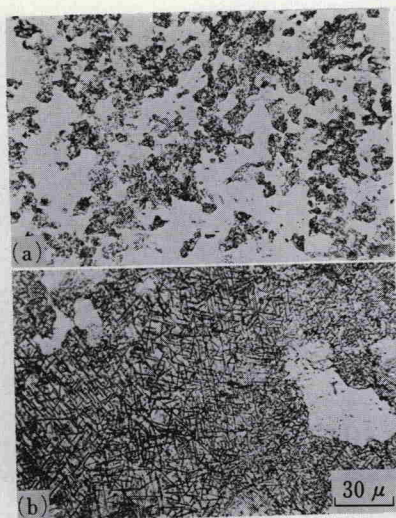


Photo. 9. Microstructures observed in Fe-0.99%C alloy (a) and 1.11%C steel (b) treated isothermally at 38.5 kbar

- (a) Carbide and aggregate; 500°C×2 min
- (b) Carbide and aggregate; 450°C×3 hr

the pressure was increased to 38.5 kbar, either spherical or acicular carbide was observed in the specimen austenitized at 950°C and then transformed at 500°C. The electron micrographs in Photo. 7 show that this change of the shape of carbide was affected by the austenitizing temperature prior to the isothermal transformation under high pressure. It seems that when the austenitizing temperature was relatively lower, the pre-existed carbides remained indissolve and the spherical carbides were grown from them during the isothermal treatment, and oppositely that when the pre-existed carbides dissolved completely in the austenite matrix at relatively higher temperature, the newly nucleated acicular carbides would be formed. It is also implied that under the pressure of about 40 kbar the A_{cm} line would exist at 950°C for this steel, and this could result in the formation of these two shapes of carbide according as a slight difference of the experimental conditions. However, as described above, such a change was observed only in the commercial steel SK3 and did not in the high purity alloy A-9. Although it will be discussed later again, the true reason for this phenomenon is not obvious yet. Only for the SK3 steel at 38.5 kbar, the austenitizing temperature was increased to 1 050°C in this study. Photograph 8 shows a typical acicular carbide structure obtained in SK3 steel.

The structures of the A-9 alloy and SK3 steel transformed isothermally at a temperature below the nose and at 38.5 kbar are shown in Photo. 9. These are the "aggregate" structures containing the primarily precipitated carbides, and no "columnar bainite" could be observed in these high carbon specimens even though the pressure was decreased to 29 kbar.

4. Summary of the Structures

The structures obtained at examined high pressures are summarized in Tables 2 and 3. In these tables

Table 2. The temperature range in which various structures are observed in isothermal transformation of Fe-C alloys under high pressures. Experiments were carried out at every 50°C. Data at 1 atm are also shown for reference.

Sample °C \ Pressure	A-2		(1)	A-4		(2)	A-9	
	29 kbar	38.5 kbar	1 atm	29 kbar	38.5 kbar	1 atm	29 kbar	38.5 kbar
700			↑↑			↑↑		
650	↑ P	↑ P	↑ F P	↑ P	↑ P	↑ C P	↑ C P	↑ C P
600								
550								
500								
450	↓ AG	↓ AG		↓ AG		↓ FB		↓ AG
400				↓ AG				
350	↓ CB	↓ CB		↓ CB		↓ AB		
300								

* P=pearlite, AG=aggregate, CB=columnar bainite, C=carbide, F=ferrite, FB=feather bainite, AB=acicular bainite

** Samples

- (1) 0.50%C, 0.001%Mn, 0.01%Si (by Scott)¹⁸⁾
- (2) 0.87 to 0.89%C (by Kahles)¹⁹⁾

Table 3. The temperature range in which various structures are observed in isothermal transformation of commercial steels under high pressures. Experiments were carried out at every 50°C. Data at 1 atm are also shown for reference.

Sample °C \ Pressure	(1)	S 20 C		(2)	S 50 C		(3)	SK 3	
	1 atm	29 kbar	38.5 kbar	1 atm	29 kbar	38.5 kbar	1 atm	29 kbar	38.5 kbar
700	↑ F P			↑↑			↑↑		
650		↑ P	↑ P	↑ F P	↑ P	↑ C P	↑ C P	↑ C P	↑ C F
600									
550									
500									
450		↓ AG	↓ AG	↓ FB	↓ AG	↓ AG	↓ FB	↓ AG	↓ AG
400									
350							↓ AB		
300									

* P=pearlite, AG=aggregate, CB=columnar bainite, C=carbide, F=ferrite, FB=feather bainite, AB=acicular bainite

** Samples

- (1) 0.25%C, 0.54%Mn, 0.022%P, 0.035%S, 0.14%Si (by Christenson)²⁰⁾
- (2) 0.5%C, 0.91%Mn (by Wilks)²¹⁾
- (3) 1.18%C, 0.76%Mn, 0.011%P, 0.029%S, 0.029%Si, 0.009%Mo (by Blanchard)²²⁾