haviour of high purity Fe–C alloys and commercial steels. Special emphasis is placed on the determination of TTT diagrams and on the observation of structure changes caused by pressure. In addition, the behaviour of carbides which appeared during isothermal transformation is also discussed.

II. Experimentals

1. Materials

The materials used in this study were three high purity Fe–C alloys containing 0.28, 0.42 and 0.99%C respectively, and three commercial steels (JIS S20C, S50C, and SK3) having nearly the corresponding carbon contents to those of the alloys. The chemical composition of them are shown in Table 1. On the basis of the phase equilibria of Fe–C system under high pressure shown in Fig. 1, the carbon content in these materials was chosen so as to obtain the following at 1 atm, and at 29 and 38.5 kbar:

(1) Showing a hypoeutectoid structure at 1 atm, but a nearly eutectoid structure is expected under high pressure. (A–2, S20C)

(2) Showing a hypoeutectoid structure at 1 atm, but a hypereutectoid structure is expected under high pressure. (A–4, S50C)

(3) Showing hypereutectoid structures regardless of the change of pressure. (A–9, SK3)

The Fe–C alloys were melted in a high frequency vacuum furnace with the electrolytic iron and a Fe–C mother alloy (5%C) which had been prepared beforehand, and cast to 6 kg ingots. These ingots were heat treated and hot and cold worked to 3 mmϕ rods by rolling, swaging and drawing. The commercial steel bars of 40 mmϕ were also finished to 3 mmϕ rods in the same manner as that of the alloys. These rods were normalized in a vacuum furnace and used to the high pressure experiments.

Table 1. Chemical compositions of materials used

Specimen	C	Si	Mn	P	S
A–2	0.28	0.001	0.004	0.001	0.002
A–4	0.42	0.001	0.01	0.001	0.003
A–9	0.99	0.001	0.03	0.001	0.003
S 20C	0.25	0.26	0.60	0.021	0.011
S 50C	0.49	0.21	0.49	0.010	0.016
S K3	1.11	0.23	0.50	0.022	0.009

2. Experimental Procedures

The experiments were carried out with a " girdle " type high pressure apparatus which had been described in detail in previous papers.[12,13] Two specimens, 3 mm in diameter and 3 mm in length, were inserted into a graphite tubular resistance furnace of nearly the same size with them, and were surrounded by pressure transmitting media such as talc and pyrophillite to compose the pressure cell.

The pressure in the cell was calibrated at room temperature by measuring the press load required to induce the transitions of Bi (I–II) at 25.4 kbar, Tl (II–III) at 37 kbar, and Ba(II–III) at 59 kbar.

The temperature in the cell was measured with an alumel–chromel thermocouple, because the thermal electromotive force of this couple is less affected by pressure than that of others,[14] and the correction was done by the Hanneman's method.[14]

The isothermal transformation under high pressure was carried out according to the following program; the specimens were pressurized up to a proposed pressure at room temperature, austenitized at 950°C for 20 min, rapidly cooled to 650° or 250°C, held for various time up to 24 hr, quenched to the room temperature and finally released the pressure.

By switching off the electric current for heating directly the graphite furnace, the cooling rate of the specimen from 950° to 200°C was attained to about 200°C/sec.

The microstructure was examined by optical and electron microscopy, and TTT diagrams at 29 and 38.5 kbar were determined. The change of the characteristic points in Fe–C alloys and steels was calculated beforehand; on the former, A_1 points by Kaufman's method[10] and Ms points by Radcliffe's equation[11] as shown in Fig. 1, while on the latter, Ms points by Predmore's equation.[15]

In order to observe the microstructure transformed under high pressure by transmission electron microscopy, discs of 0.3 mm thick were cut out from the treated specimens and thin foils were prepared by chemical and electrolytic polishing.

III. Results

1. Fe–0.28%C(A–2) Alloy and S20C Steel

The A–2 alloy and S20C steel were expected to show the entirely eutectoid structure at the examined

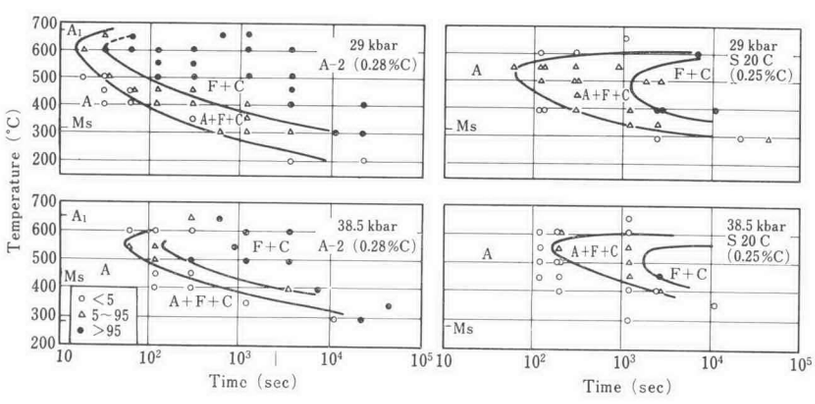

Fig. 2. TTT diagrams obtained in Fe–0.28%C alloy and 0.25%C commercial steel under high pressure

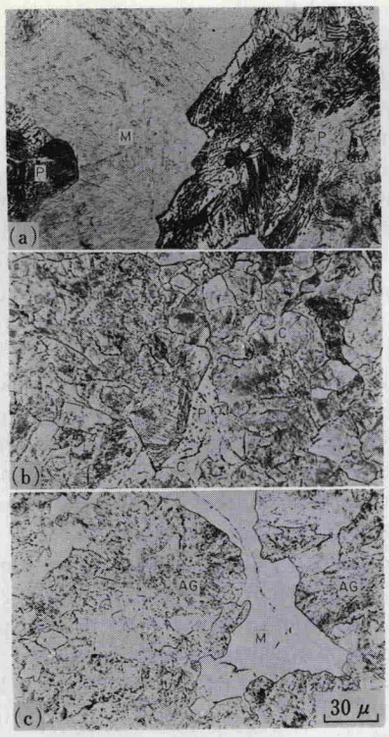

Photo. 1. Microstructures observed in Fe–0.28%C alloy treated isothermally at 29 kbar
(a) Pearlite (P) in martensite matrix (M); 650°C× 30 sec
(b) Pearlite (P) and carbide (C); 600°C×2 min
(c) Aggregate structure (AG) in martensite matrix (M); 500°C×2 min

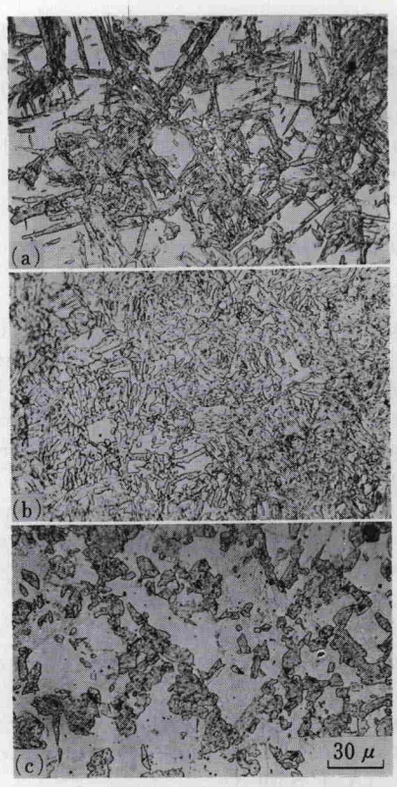

Photo. 2. Microstructures observed in Fe–0.28%C alloy (a) and 0.25%C steel (b), (c) treated isothermally under high pressure
(a) Columnar bainite; 29 kbar, 300°C× 10 min
(b) Columnar bainite; 29 kbar, 350°C×20 min
(c) Aggregate; 38.5 kbar, 450°C×20 min

high pressure. The TTT diagrams obtained at 29 and 38.5 kbar are shown in Fig. 2. These diagrams show nearly the same C-shaped curve with that of a eutectoid steel at 1 atm. It is shown in these diagrams that, by an increase of the pressure from 29 to 38.5 kbar, the incubation time generally increased about five times and the temperature at the nose lowered to about 25°C.

This temperature drop at the nose was nearly equal to the drop of A_1 temperature caused by above increase of pressure. Comparing the incubation time before the transformation starts in A–2 alloy with that in S20C steel at the same pressure level, the latter shows far larger retardation on the progress of transformation. Such a difference is thought to be due to the effect of impurities in S20C steel, because the grain size in both specimens was identical. In this experiment, as the measurement of austenite grain size under high pressure was very difficult, it was estimated from the martensite structure obtained by quenching the specimens from austenitized temperature.

The microstructures observed in A–2 alloy isothermally transformed at 29 kbar are illustrated in Photo. 1. Photograph 1 (a) and (b) show the example of structures transformed in a temperature range above the nose, in which range wholly pearlitic structure would be expected.

In Photo. 1 (a), it is observed that the alloy did not fully transformed yet and the structure is a mixture of pearlite and martensite. In this photograph, no proeutectoid ferrite or carbide are observed. On the other hand, Photo. 1 (b) shows the structure after completely transformed, and the arrows indicate the carbides precipitated at prior austenite grain boundaries or sub-boundaries. These precipitates increased with an increase of the holding time. However, this tendency was weakened when the pressure was increased or the commercial steel was subjected to the experiment.

Photograph 1 (c) shows a singular structure obtained at the temperature below the nose. This structure consists of a gathering of irregular-shaped ferrite and carbide, and is similar to the one which was already reported by Radcliffe[5] as " aggregate " structure. Photograph 2 shows the other singular structures which were obtained after the isothermal transformation in a temperature range a little higher than Ms. This range corresponds to the one in which the acicular bainite would be expected at atmospheric pressure. Nilan[6] named this structure as " columnar bainite ". In these photographs, typical columnar bainite structure is observed in both Photos. 2 (a) and (b). However, the columnarity of this structure decreased with an increase of pressure as shown in Photo. 2 (c), and the structure became rather resembled to the " aggregate ".

2. Fe–*0.42%*C(*A–4*) *Alloy and S50C Steel*

These materials were chosen on the basis of an expectation that the structure would be changed from