

formation is completed at $M_f^{\gamma \rightarrow \epsilon'}$ point (i) and during releasing of pressure, $\epsilon' \rightarrow \alpha'$ transformation occurs because of passing through the $M_f^{\epsilon' \rightarrow \alpha'}$ point (j). In this work, both γ and ϵ' phases were not detected in the X-ray analysis of all the alloys pressurized. Consequently, the only α' phase existed in these alloys at atmospheric pressure as a result of $\gamma \rightarrow \epsilon'$ and $\epsilon \rightarrow \alpha'$ transformation during the release of pressure or during cooling under high pressure. It is thought that 41 kbar at which only plate-like structure was obtained corresponds to the condition of 3.

On the other hand, the $\gamma \rightarrow \epsilon' - \alpha'$ transformation is observed in Fe-Mn and Fe-Ni-Cr alloys even at atmospheric pressure.²³⁾⁴⁾ From this results, it can be considered that this pressure for these alloys is equivalent to condition of 3 in Fig. 7. This fact means that the observation of the transformation caused in high alloy at atmospheric pressure is also possible in low alloy under high pressure.

It was described above that the plate-like structure of martensite is formed after $\gamma \rightarrow \epsilon' - \alpha'$ transformation under high pressure. Here, the following two processes producing this structure will be discussed. The first is a case in which the plate-like structure will be formed during tempering of ϵ' phase at 300°C, which was precipitated in $\gamma \rightarrow \epsilon'$ transformation during prior quenching. However, when the ϵ' phase is reheated at 300°C, it must be transformed to γ phase at this temperature. Thus, the first case is not likely to occur. In the second case, considered that the structure will be as a result of formation of twin during the relief of strain which is accumulated around the lenticular structure due to the volume expansion in $\gamma \rightarrow \alpha'$ transformation. However, this process is also un-

likely to occur, because as the twin forms without the volume change, the pressure does not enhance the formation of twins.

Finally, the results were summarized schematically on P-T diagram for low carbon alloy in Fig. 8. From this figure, the relationship between the process of transformation and various martensite structure, could be understood.

5. Conclusion

- (1) The Ms-temperature was lowered approximately 40 °C/10 kbar in all alloys pressurized in this experiment and its tendency was not significantly affected by alloying elements.
- (2) The difference between measured Ms-temperature and calculated one under the conditions of various was fluctuated between 30 to 60°C. It is, however, possible to estimate Ms-temperature of low alloys by using Predmore's equation.
- (3) The microhardness of martensite structures increases with an increase of pressure. This might be as a result of the lowering of Ms-temperature by pressure, accompanying with the change of martensite structure.
- (4) The structural changes of martensite, caused by pressurizing can be explained qualitatively by P-T diagram of iron. With an increase of pressure the change from packet structure to plate-like one was observed in the alloys containing carbon less than 0.3%. In the alloys containing carbon more than 0.3%, the change from mixed lenticular and plate-like structure to plate-like structure was observed. It is thought that the plate-like structure was observed in the martensite formed by $\gamma - \epsilon' - \alpha'$ transformation. The pressure at which this structure appears, is affected by alloying elements and the effect becomes stronger in the order of Mn, Cr and Si addition.

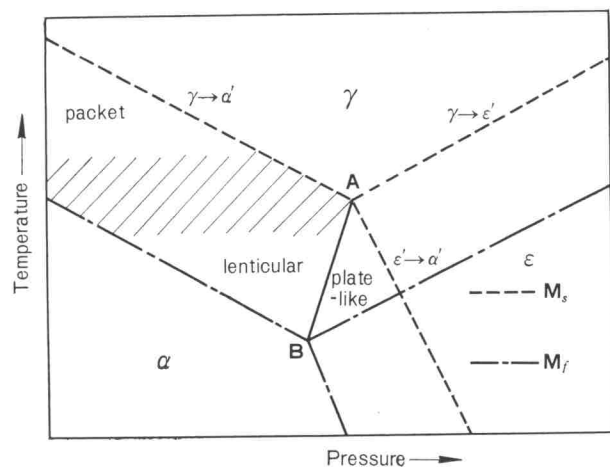


Fig. 8. A schematic illustration of the region with various types of martensite on P-T diagram for a low carbon alloy.

References

- 1) W. A. Basett and T. Takahashi: ASME Paper, 64-WA/PT-24, (1964), New York ASME.
- 2) P. M. Giles, M. H. Longenbach, and A. R. Mader: J. Appl. Phys., **42** (1971) 11, 4290.
- 3) H. Schuman: Arch. Eisenhüttenw., **38** (1967) 8, 647.
- 4) Y. Imai and S. Hanada: J. Japan Inst. Metals (1973) 4, 422 (in Japanese)
- 5) L. Kaufman, A. Leyenaar, and J. S. Harvy: "Progress in Very High Pressure Research", ed. by F. P. Bundy, et al., (1961) 90.
- 6) S. V. Radcliffe and M. Schatz: Acta Met. **10** (1962) 3, 210.
- 7) E. Scheil and W. Norman: Arch. Eisenhüttenw., **30** (1959) 12, 751.
- 8) J. S. Pascover and S. V. Radcliffe: Acta Met., **17** (1969) 3, 321.

- 9) T. P. Yershova and E. G. Ponyatovskij; Russian Metallurgy, 4 (1967), 81.
- 10) R. E. Predmore and E. P. Kler: Trans. ASM (1969), 768.
- 11) W. F. Claussen: "High Pressure Measurement", ed by A. A. Giardini and E. C. Lloyd, (1963), 125 Butterworth.
- 12) M. Fujita and M. Suzuki: Tetsu-To-Hagané, 57 (1971) 10, 1676 (in Japanese)
- 13) M. Suzuki and M. Fujita: Proceedings of ICSTIS, Part II (1971), 1165.
- 14) A. S. Kenneford: JISI, 189 (1958) 7, 135.
- 15) P. M. Giles and A. R. Marder: Met. Trans., 2 (1971) 5, 1371.
- 16) R. C. Ruhl and M. Cohen: Acta Met., 15 (1967) 2, 159.
- 17) M. Suzuki and M. Fujita: Tetsu-To-Hagané, 53 (1967) 7, 912 (in Japanese)
- 18) H. Nakajima and T. Araki: Tetsu-To-Hagané, 51 (1965) 11, 2130 (in Japanese)
- 19) W. Steven and A. G. Haynes: JISI, 183 (1956) 8, 349.
- 20) L. Kaufman and M. Cohen: Trans. AIME 206 (1956) 10, 1393.
- 21) L. Kaufman, S. V. Radcliffe, and M. Cohen: "On Decomposition of Austenite by Diffusional Process" in AIME Symp., (1960), 313.
- 22) R. F. Vyhna and S. V. Radcliffe: Acta met., 15 (1967) 9, 1475.
- 23) A. Holden, J. D. Bolton, and E. R. Petty: JISI, 209 (1971) 9, 721.
- 24) A. R. Marder and G. Krauss: Trans. ASM, 60 (1967), 651.
- 25) P. M. Kelly and J. Nutting: JISI, 197 (1961) 3, 199.
- 26) L. D. Blackburn, L. Kaufman, and M. Cohen: Acta Met., 13 (1965) 5, 533.
- 27) G. L. Stepakoff and L. Kaufman: Acta Met., 16 (1968) 1, 13.
- 28) L. Hyspe ká and K. Mazance: Arch. Eisenbüttew., 41 (1970) 4, 339.

Appendix

Predmore's equation used in this study is as follows:

$$\begin{aligned} \Delta G_{(x, T, P)}^{\alpha \rightarrow \gamma'} &= 1 - (X_{Cr} + X_C + X_{Si} + X_{Mn}) \\ & (1.202 - 2.63 \times 10^{-3} T^2 + 1.54 \times 10^{-6} T^3) \\ & + X_{Cr} (460 + 1.0 T) + X_{Cr} (1 - X_{Cr}) (-2800 + 0.75 T) \\ & + 450 X_{Si} \\ & - 2700 X_{Mn} \\ & + RT \left[X_C \ln \left(\frac{3 - X_C (3+z)}{1 - 6 X_C} \right) + \left(\frac{1 - X_C}{3} \right) \ln \left(\frac{1 - 6 X_C}{1 - X_C} \right) \right. \\ & \left. - \frac{3(1 - X_C)}{z} \ln \left(\frac{3 - X_C (3+z)}{3(1 - X_C)} \right) \right] \\ & - 24.P \left[\Delta V_{293K}^{\alpha \rightarrow \gamma'} - 2 \times 10^{-4} (T - 293) \right] \dots \dots \dots (1) \end{aligned}$$

List of Symbols

$\Delta G_{(x, T, P)}^{\alpha \rightarrow \gamma'}$	Free energy change for $\alpha \rightarrow \gamma$
T	Temperature ($^{\circ}K$)
P	Pressure (kbar)
X_{Cr}	Atomic fraction of solute (Cr)
X_C	Atomic fraction of solute (C)
X_{Si}	Atomic fraction of solute (Si)
X_{Mn}	Atomic fraction of solute (Mn)
R	Gas constant
z	Exclusion parameter ($z = s - 1$)
s	Number of neighboring sites excluded by the occupancy of a given interstitial site
$\Delta V_{293K}^{\alpha \rightarrow \gamma'}$	Change in molar volume for $\alpha \rightarrow \gamma$ ⁶⁾

