Autoradiographs of martensite indicate a random distribution of carbon in austenite with no abnormal grain boundary effects. None of the autoradiographs of specimens carburized above the α -to- γ transformation temperature in pure iron gave any evidence of accelerated grain boundary diffusion of carbon in austenite.

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References

- ¹ J. S. Arnold: An Improved Technique for Liquid Emulsion Autoradiography. *Proceedings Soc. for Experimental Biology and Medicine* (1954) 85, pp. 113-116.
- ² G. C. Towe, H. J. Gombert, and J. W. Freeman: High Resolution Autoradiography. *Technical Note 3209 NACA* (July 1954).

Technical Note

Effect of Cooling Rate on Hardness of Commercial Titanium Alloys

by Howard Martens

HARDNESS behavior of commercial titanium alloys following various heat treating processes has been studied for some time. However, the hardness of such alloys following a definite measured cooling rate from the single phase β region has not been reported. Therefore, a series of experiments was conducted on the three alloys: 150A, 130A, and 130B. The manufacturers gave the following compositions for these alloys: Ti 150A: 0.045 pct C, 0.069 pct N, 1.32 pct Fe, and 2.68 pct Cr; RC 130A: 0.13 pct C, and 7.9 pct Mn; RC 130B: 0.11 pct C, 3.5 pct Mn, and 3.2 pct Al. A method similar to that described by Greninger¹ was used, and the cooling rate varied from 6° to 9200°F per sec. The cooling curves were recorded on a Speedomax or a recording oscillograph, and the hardness was measured on a Tukon hardness tester using a Knoop indenter with a 500 g load.

The curves of Fig. 1 show the variation of the Knoop hardness with the cooling rate for these three alloys. The alloys 150A and 130B behave in a similar manner, as shown by the curves. In neither of these alloys was it possible to retain the high temperature β phases, even by the most rapid cooling rate. The slow cooling rates produced a typical $\alpha + \beta$ structure in these two alloys. As the cooling was increased, these phases became more finely dispersed and the hardness increased. This increase in hardness with cooling rate continued for the 150A alloy until a rate of approximately 1000°F per sec was reached. At this cooling rate, the structure showed the result of the diffusionless transformation of the β solid solution to the supersaturated α' solid solution which is referred to as α' . At higher cooling rates, the structure showed no change and the hardness showed no great change, as indicated by the dotted portion of the curve in Fig. 1. The increase in hardness with cooling rate for the 130B alloy continued until a rate of approximately 300°F per sec was reached. At this rate the α' structure was produced and the maximum hardness was reached. Higher cooling rates caused no marked changes in hardness or structure.

The alloy 130A behaved in a different manner, as shown by the curve of Fig. 1. The structure produced by the slow cooling rates was a typical $\alpha + \beta$ structure, which became finely dispersed as the cooling rate increased. The hardness increased with

Fig. 1—Curves show the variation of Knoop hardness with cooling rates from 2000°F for alloys Ti 150A, RC 130A, and RC 130B.

cooling rate and reached a maximum at approximately 120°F per sec. At this maximum hardness, the structure showed the result of the decomposition of the β phase into the $\beta + \omega$ phase structure. As the cooling rate was increased, smaller amounts of the ω phase were formed and the alloy became softer. For cooling rates of 3000°F per sec and above, the high temperature β phase was retained and the hardness of the alloy did not change markedly.

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¹ A. B. Greninger: The Martensite Thermal Arrest in Iron-Carbon Alloys and Plain Carbon Steels. *Trans. ASM* (1942) 30, pp. 1-26.