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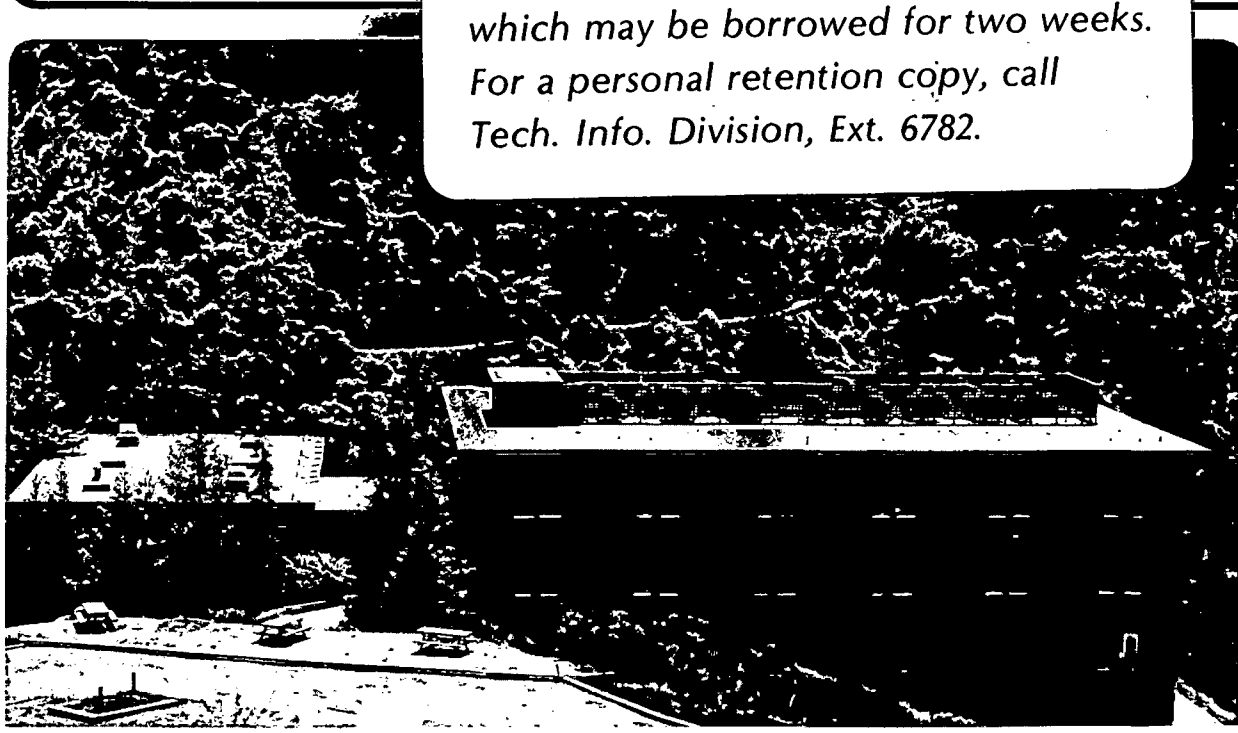

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ABSTRACT

The results of both welding and weld simulation studies on 2BT-treated 9Ni steel show that multiple rapid thermal cycles have a very beneficial effect on heat-affected zone toughness at cryogenic temperatures. The metallurgical sources of toughness are, however, different from those in the furnace-treated base plate. The rapidly-cycled material contains no detectable austenite phase. The alloy is grain-refined by the rapid thermal cycle, and the matrix carbon content is relieved by the formation of interlathcementite precipitates which do not destroy toughness.

INTRODUCTION

The heat treatment of 9Ni steel for cryogenic use is usually finished by an intercritical temper at a temperature near 600°C which introduces a distribution of thermally stable austenite along the martensite lath boundaries. This austenite serves two functions: it refines the effective grain size of the steel by disrupting the crystallographic alignment of martensite packets, hence lowering the ductile-to-brittle transition temperature [1], and it getters carbon from the lattice, hence raising the upper-shelf toughness [2]. The influence of the precipitated austenite is sufficiently strong that 9Ni steel has excellent toughness at temperatures as low as 77K in the simple quench-and-tempered (QT) condition. To achieve reasonable toughness at lower temperature, i.e., 4.2K, however, the austenite effect must be supplemented by a prior grain refinement. Promising results have been obtained at 4.2K through use of the π2BTπ treatment developed in this laboratory [3] in which a four-step thermal cycling treatment is used to refine the effective grain size [4] prior to the final temper.

Recent research in Japan [5,6] has shown that 9Ni steel may also be welded with matching ferritic filler metals using a multipass gas tungsten arc (GTA) welding process to establish good toughness at 77K. A similar welding procedure was applied to 2BT-treated 9Ni steel [7] and it led to high impact toughness at 4.2K. In these cases the rapid, multiple thermal cycling imposed on the weld metal and HAZ by the sequential weld passes is presumably responsible for the good cryogenic toughness of the welded joint. Careful metallographic characterization of the GTA-welded 2BT material [7] showed, however, that no measurable austenite is present either in the HAZ near the fusion zone or in the weld metal. The metallurgical source of the high toughness of the weld metal and, hence, HAZ must differ from the source in the heat-treated base plate.

The present work was undertaken to clarify the toughening mechanism in the HAZ through analysis of the 2BT-treated material given rapid thermal cycles to simulate the multiple heat cycles imposed during GTA welding.

EXPERIMENTAL PROCEDURE

The 9Ni steel used in this work was a commercial grade supplied by Nippon Kokan, K.K. Its detailed composition was: Fe-8.49Ni-0.45Mn-0.24Si-0.059C-0.006P-0.004N-0.002S-0.0020. The material was supplied in the QT condition; it was given a 2-hr solution anneal at 900°C to establish a starting structure for the 2BT treatment [3]: 730°C, 1 hr + 650°C, 2 hrs + 730°C, 1 hr + 650°C, 2 hrs + 575°C, 1 hr. The fully heat-treated plates were then cut into slightly oversized Charpy impact specimens in longitudinal orientation which were given rapid thermal cycling treatments in an induction furnace [8]. Samples cycled to temperature greater than 800°C were heated at 50°C/sec; those cycled to T_{max} <800°C were heated at 27°C/sec.

Charpy impact tests were conducted on the treated specimens at 77K according to ASTM specification E-23. Analytic specimens were cut from the broken Charpy specimens. The austenite fraction was determined by x-ray diffraction and the microstructure was studied through transmission electron microscopy.

RESULTS

Single cycle. The retained austenite content and the 77K Charpy impact toughness are plotted as a function of peak temperature in a single thermal cycle (Fig. 1). Peak temperatures below the A_S temperature (~ 630 °C) caused no apparent change in the alloy--both the 77K Charpy impact energy and the fraction of retained austenite remained unchanged. Above 630°C the retained austenite content dropped precipitously, and no retained austenite was detected for peak temperatures above the A_f temperature (~715°C). The 77K Charpy impact ~65 ft-lb (88 joules) at 730°C which was preserved until the peak temperature exceeded 1000°C. While the impact toughness was relatively low over the range 715-1000°C the fracture mode was ductile rupture, showing that the ductile-to-brittle transition temperature remained below 77K. Above 1000°C grain growth was observed. Peak temperatures above 1200°C led to large prior austenite grain sizes (up to 400 μm0 resulting in very low toughness in a brittle fracture mode--the ductile-brittle transition temperature was raised above 77K.

These results suggest that the destruction of the 2BT structure on rapid cycling occurs in two steps. For peak temperatures in the range 650-715°C the precipitated austenite disappears causing a decrease in upper-shelf toughness while preserving a fine effective grain size and a low ductile-brittle transition temperature. The fine substructure begins to be destroyed at peak temperatures above 1000°C, causing a further loss in toughness due to an increase in the transition temperature.

Multiple cycles. In order to simulate the microstructure in the heat-affected zone near the fusion line of a multipass weldment, specimens that had been rapidly cycled to 1200°C were given additional thermal

cycles to lower peak temperatures. The multiple cycling treatments were selected on the basis of work done by Tamura, et al. [9] on quench-and-tempered 9Ni steel, and are shown on the x-axis (Fig. 2). The y-axis plots the 77K Charpy values as a function of the heat treatment, and it also shows that no retained austenite was detected in any of the thermally-cycled specimens.

The results of the multiple-cycle heat treatments resemble those obtained from single cycle treatments (Fig. 1), but reflect different metallurgical mechanisms. The addition of an 800°C (higher than A_f) cycle raises the impact energy to ~70 ft-lb (95 joules) and changes the failure mode to ductile fracture by micro-void coalescence. The dominant microstructural change wrought by this thermal cycle is a refinement of the effective grain size. Optical microscopy reveals a martensite packet size of ~ μm--transmission electron microscopic studies (still in progress) suggest a further refinement of the effective grain size through a partial destruction of the lath alignment within martensite packets. The grain refining effect of an $\alpha \rightarrow \gamma \rightarrow \alpha$ cycle is, of course, well known [10,11] though its details are not fully understood.

The toughness is further improved, to 150 ft-lb (203 joules), by a third rapid cycle to 600°C. Transmission electron metallograph (Fig. 3) shows that the principal microstructural change after the 600°C cycle is the aggregation of carbon into cementite precipitates along the lath and packet boundaries. No austenite spots appear in the diffraction pattern (Fig. 3c). The dramatic improvement in toughness contrasts with the negligible effect of a 600°C cycle imposed directly on a sample which had not experienced the intermediate 800°C treatment (Fig. 2). The result suggests that the 600°C cycle is useful for raising the toughness of a sample which fractures in a ductile mode (after the 800°C treatment) but is ineffective in lowering the ductile-to-brittle transition.

CONCLUSION

Previous research on the influence of precipitated austenite on the cryogenic toughness of intercritically tempered steels yields the conclusion that the austenite is beneficial because of its microstructural consequences: it refines the effective grain size, hence lowering the ductile-to-brittle transition, and it getters carbon and deleterious carbides from the matrix, hence raising the upper-shelf toughness. It follows that any other metallurgical treatment that achieves similar microstructural changes should lead to similar cryogenic properties. In the case of rapidly thermal cycled 9Ni steel, a cycle to above the A_f temperature (715°C) suffices to refine the effective grain size and decrease the transition temperature while a subsequent cycle to below the A_s temperature (630°C) getters carbon into interlath cementites and raises the upper shelf toughness. Both treatments are necessary in 9Ni steel. A single cycle to 800°C establishes a ductile fracture mode at 77K but leaves a low upper-shelf impact toughness. A single cycle to 600°C is not helpful because it does not eliminate the brittle fracture mode at 77K.

The results represented here suggest a simpler interpretation for the high toughness of the heat-affected zone in multipass welded 9Ni steelμ while the precipitated austenite is removed by the weld heat

cycles, the sequential rapid heat cycles to successively lower peak temperatures associated with succeeding weld passes reestablish high toughness by sequentially refining the effective grain size and gettering carbon into interlath cementites. Further research is, however, needed to clarify the details of this process in actual multipass welded plates.

ACKNOWLEDGEMENTS

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REFERENCES

1. J.W. Morris, Jr., C.K. Syn, J.I. Kim and B. Fultz: Consequences of the Re-transformation of Precipitated Austenite in Ferritic Cryogenic Steels, in **Proc. Internat'l Conf. on Martensitic Transformations**, Cambridge, MA (1979) pp. 572-577.

2. J.I. Kim and J.W. Morris, Jr.: On the Scavenging Effect of Precipitated Austenite in a Low Carbon Fe-5.5NI Alloy, Met. Trans. A, vol. 11A (1980) pp. 1401-1406.

3. C.K. Syn, S. Jin and J.W. Morris, Jr.: Cryogenic Fracture Toughness of 9Ni Steel Enhanced through Grain Refinement, Met. Trans. A, vol. 7A (1976) pp. 1827-1832.

4. S. Jin, J.W. Morris and V.F. Zackay: Grain Refinement through Thermal Cycling in an Fe-Ni-Ti Cryogenic Alloy, Met. Trans. A, vol. 6A (1975) pp. 141-149.

5. Nippon Kokan, K.K.: Matching Ferritic Consumable Welding of 9% Nickel Steel to Enhance Safety and Economy, 1980 AWS 61st Annual Meeting, Session 22 (1980).

6. Kobe Steel LTD.: Practicability of Ferritic Filler for Welding 9%Ni Steel Plates, 1980 AWS 61st Annual Meeting, Session 22 (1980).

7. H.J. Kim, C.K. Syn and J.W. Morris, Jr.: Ferritic Weldment of Grain-Refined Ferritic Steels for Cryogenic Use, LBL Report #13017, Lawrence Berkeley Laboratory, University of California, Berkeley, CA (1981).

8. H.J. Kim and J.W. Morris, Jr.: The Development of a Ferritic Consumable for Welding Grain-Refined Fe-12Ni-0.25Ti to Retain Toughness at 4.2°K, Welding Journal, in press (1983).

9. H. Tamura, T. Onzawa and S. Uematsu: Retained Austenite and Notch Toughness in Synthetic HAZ of 9%Ni Steel, J. Japan Welding Soc., vol. 49 919800 pp. 854-860.

10. R.A. Grange: The Rapid Heat Treatment of Steel, Met. Trans., vol 2 (1971) pp. 65-72.

11. L. F. Porter and D.S. Dabkowski: πGrain Size Control by Thermal Cyclingπ, in **Ultra Fine Grain Metals**, Syracuse University Press, Syracuse, NY (1969) pp. 133-161.

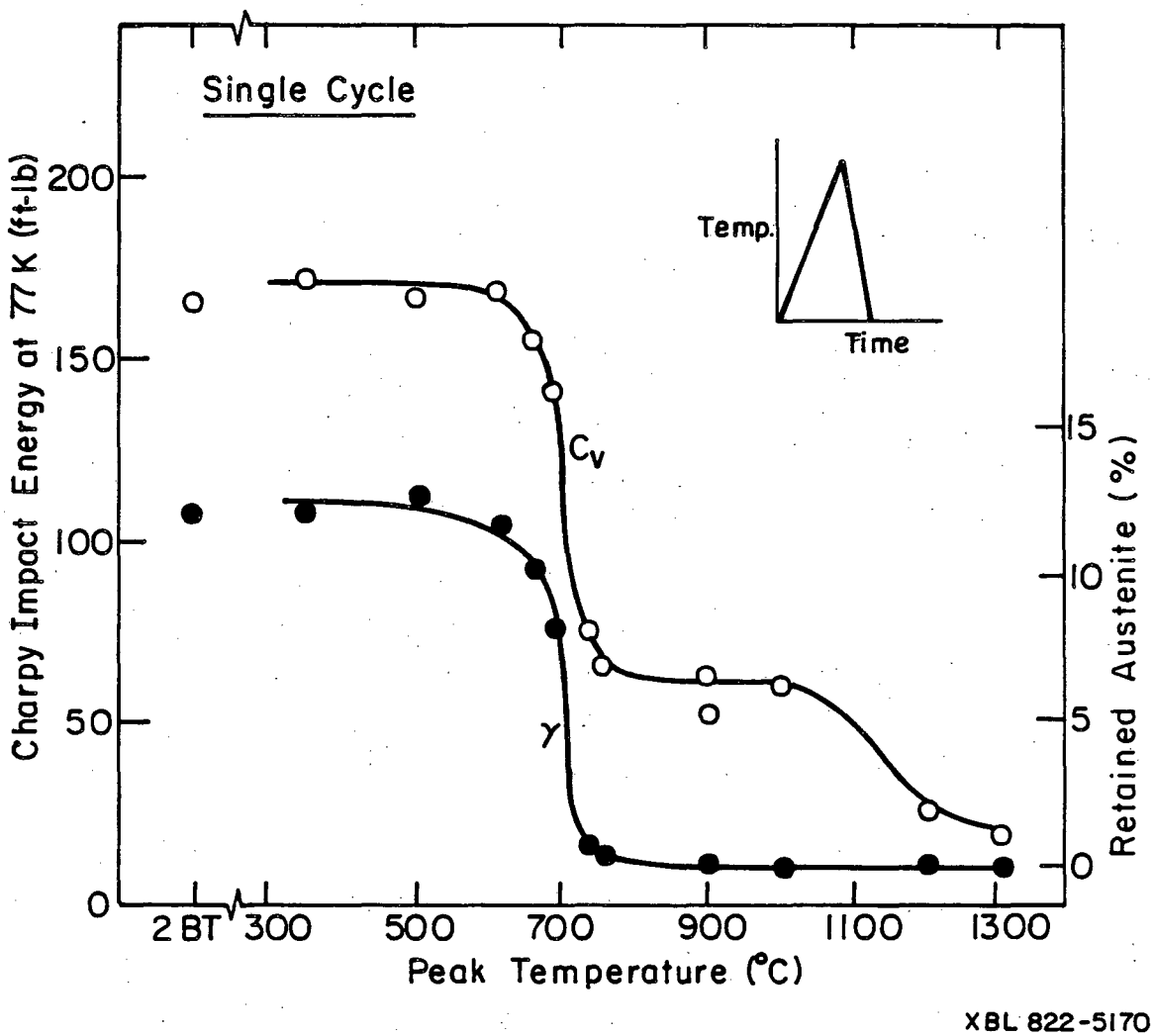

Figure 1. C_v **energy and amount of austenite vs. peak temperature of single cycle.**

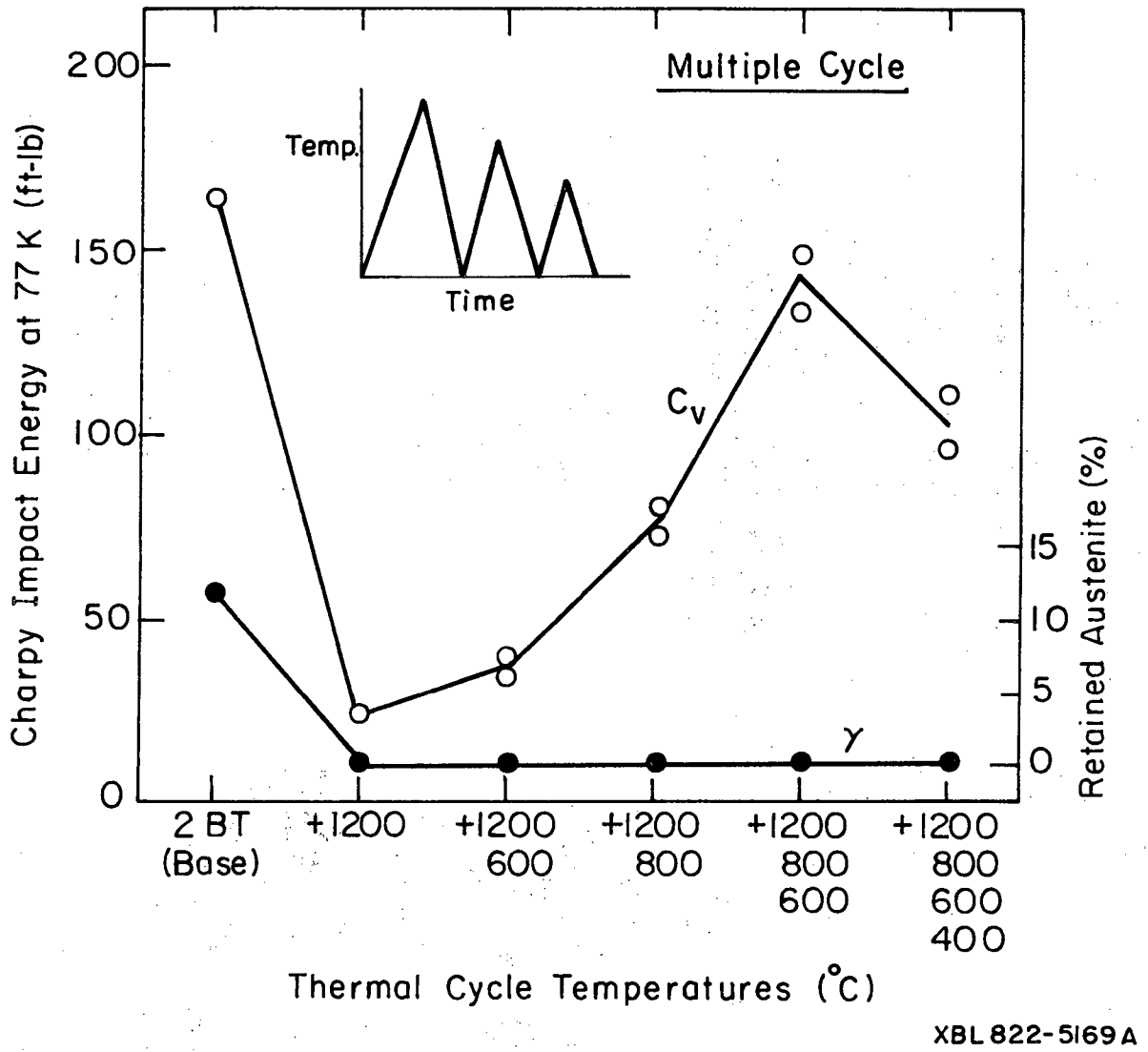

Figure 2. C_v energy and amount of austenite vs. multiple cycling treatments.

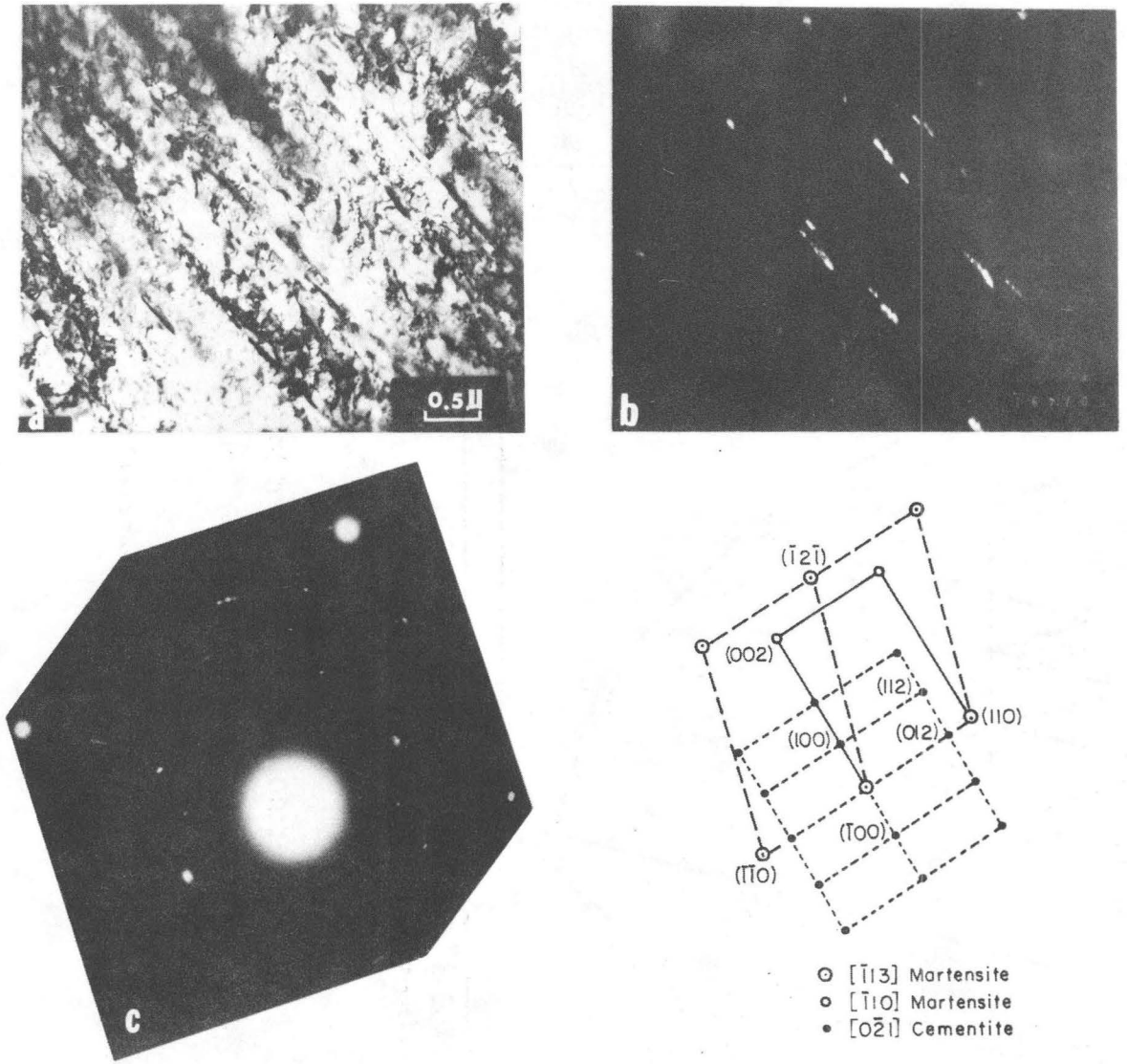

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Figure 3. TEM micrographs of cementite precipitates.

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