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The Cooling Transformations in Certain Uranium-Bearing Steels

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Reactor Materials Branch
Metallurgy Division

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U.S. NAVAL RESEARCH LABORATORY
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The Cooling Transformations in Certain Uranium-Bearing Steels

E. P. KLIER AND J. R. HAWTHORNE

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The continuous cooling transformations of three laboratory heats, containing 0, 0.06, and 1.1 percent natural uranium (U), and of a uranium-free commercial heat, following austenitizing at 1650 and 1750°F, have been investigated. The melts were prepared to the nominal composition for ASTM A212-B steel. Hardness measurements, as well as metallographic examinations, of the transformed structures were included in this study.

The two uranium-free steels yielded very similar cooling-transformation diagrams and exhibited essentially equivalent hardenability; however, the hardenability of the uranium-free commercial heat was limited by ferrite and upper bainite formation, while that of the laboratory heat was restricted by pearlite formation.

Uranium additions of 0.06 and 1.1 percent were not found to have any significant effect upon hardenability although, unlike the uranium-free laboratory heat, the hardenability of these steels was limited by upper bainite formation. Suppression of the proeutectoid ferrite reaction at intermediate cooling rates was observed to increase with uranium content.

Metallographic examinations of the 1.1-percent U steel revealed a stringer dispersion of a microconstituent, possibly Fe_2U, in all structures produced over the range of cooling conditions employed The volume of this phase was small, however, and thus is not believed to have a serious effect on austenite decomposition when quenching.

INTRODUCTION

The alloying action of uranium in low-alloy heat-treatable steels has not been studied at length (1,2), although it has been reported that a relatively moderate addition of uranium significantly retards the isothermal transformations in a 0.50-percent carbon steel (3). Since uranium fails in the periodic subgroup VIa along with chromium, molybdenum, and tungsten, steels containing uranium would be expected to possess modified austenite transformation characteristics. To examine this possibility and to provide background information for an investigation being conducted on the radiation sensitivity of uranium-bearing steels, the transformation characteristics of four steels containing graded amounts of uranium were evaluated for various cooling conditions.

NRL Problem M01-14; BuShips Project SR007-01-01-0858; ONR Project RR007-01-46, Task 5409; AEC Project AT (49-5)-2110; Army Project MIPR-ERG-5-65. The report covers one phase of the problem; work on other phases is continuing. Manuscript submitted December 23, 1964.

EXPERIMENTAL STUDIES

Four steels, of the compositions given in Table 1, were selected for study. Two of the steels were uranium-free and were included for reference (control) purposes. The eutectoid condition for uranium steels is not known but is estimated as probably in the interval under 0.2-percent uranium (U) for the 0.3-percent carbon steels (2). On the basis of this estimate, the 0.06-percent U steel would approach the eutectoid composition, while the 1.1-percent U steel would contain an excess of uranium.

The cooling-transformation dilatometer previously described (4,5) was used in the present investigation at austenitizing temperatures of 1650 and 1750°F. Transformations at the maximum cooling rates were established by thermal analysis. The hardnesses of the transformed

TABLE 1
Compositions of the Four Steels
Used in the Experiment

Mark	Percentage of Indicated Element in Each Steel									
	C	Mn	Si	P	S	Ni	Cr	Mo	U	Al
F*	0.26	0.77	0.24	0.010	0.26	0.21	0.16	0.03	-	0.08
0U	0.28	0.86	0.28	0.004	0.021	0.06	0.07	0.02	-	<0.01
0.06U	0.28	0.92	0.29	0.004	0.018	0.03	0.14	0.01	0.06	0.07
1.1U	0.27	0.91	0.30	0.003	0.020	0.06	0.05	0.01	1.1	<0.01

*Control steel.

structures were determined, and the microstructures were also examined.

RESULTS

The cooling-transformation (CT) diagrams and hardness values for the control steel (Mark F) are given in Fig. 1; the circles, squares, and triangles represent, respectively, the ferrite-pearlite, bainite, and martensite transformations on the CT diagrams. Continuous cooling curves, developed for the determination of transformations at maximum cooling rates by thermal analyses, are lettered for identification. Similarly, numbers have been assigned to the curves established in conjunction with dilatometer measurements. The dilatation-temperature curves are given in Fig. 2.

Figures 1 and 2 suggest that elevation of the austenitizing temperature from 1650 to 1750°F leads to a slight increase in the hardenability of the steel, which would result from the retardation of the proeutectoid ferrite reaction. However, the steel is a low-hardenability steel, with the depth of hardening being established by bainite formation (Figs. 3a and b). While austenitizing at 1750°F leads to some increase in hardenability, this treatment cannot be recommended for use because the steel has a mixed austenite grain size at 1750°F, as the transformed structures in Fig. 3c indicate. This coarsened structure would possess reduced fracture toughness characteristics.

The CT diagrams for the second control steel (Mark OU) are given in Fig. 4. The dilatation-temperature curves are presented in Fig. 5. For this steel the ferrite reaction is largely suppressed at the maximum cooling rates. The martensitic structures formed on drastic quenching are replaced by Widmanstätten ferrite and fine pearlite at intermediate cooling rates and by equiaxed ferrite and pearlite colonies at the minimum cooling rates (Fig. 6).

The CT of the two control steels, while yielding very similar transformation diagrams, differ significantly. For the austenitizing temperature 1650°F, the pearlite reaction is largely suppressed for intermediate cooling rates in the control steel Mark F, while in the control steel Mark OU, transformation at these cooling rates is largely to fine pearlite. Hardenability in the first steel is limited by ferrite and upper-bainite formation. In the second steel hardenability is limited by pearlite formation. The hardenabilities in the two steels are about the same, but the microstructures differ.

The CT diagrams for the 0.06-percent U steel are given in Fig. 7. The dilatation-temperature curves are presented in Fig. 8. These curves suggest that proeutectoid ferrite precipitation is largely suppressed at the intermediate cooling rates. At the maximum cooling rates martensite is formed, and as the cooling rate is reduced, upper bainite is first observed and is gradually replaced by ferrite and fine pearlite (Fig. 9). As the cooling rate is reduced to the minimum studied, the amount of ferrite increases, with the final structure consisting of equiaxed ferrite and pearlite colonies. The microstructures suggest the existence of a pseudobinary eutectoid lying in the interval 0.06 to 0.1 percent U.

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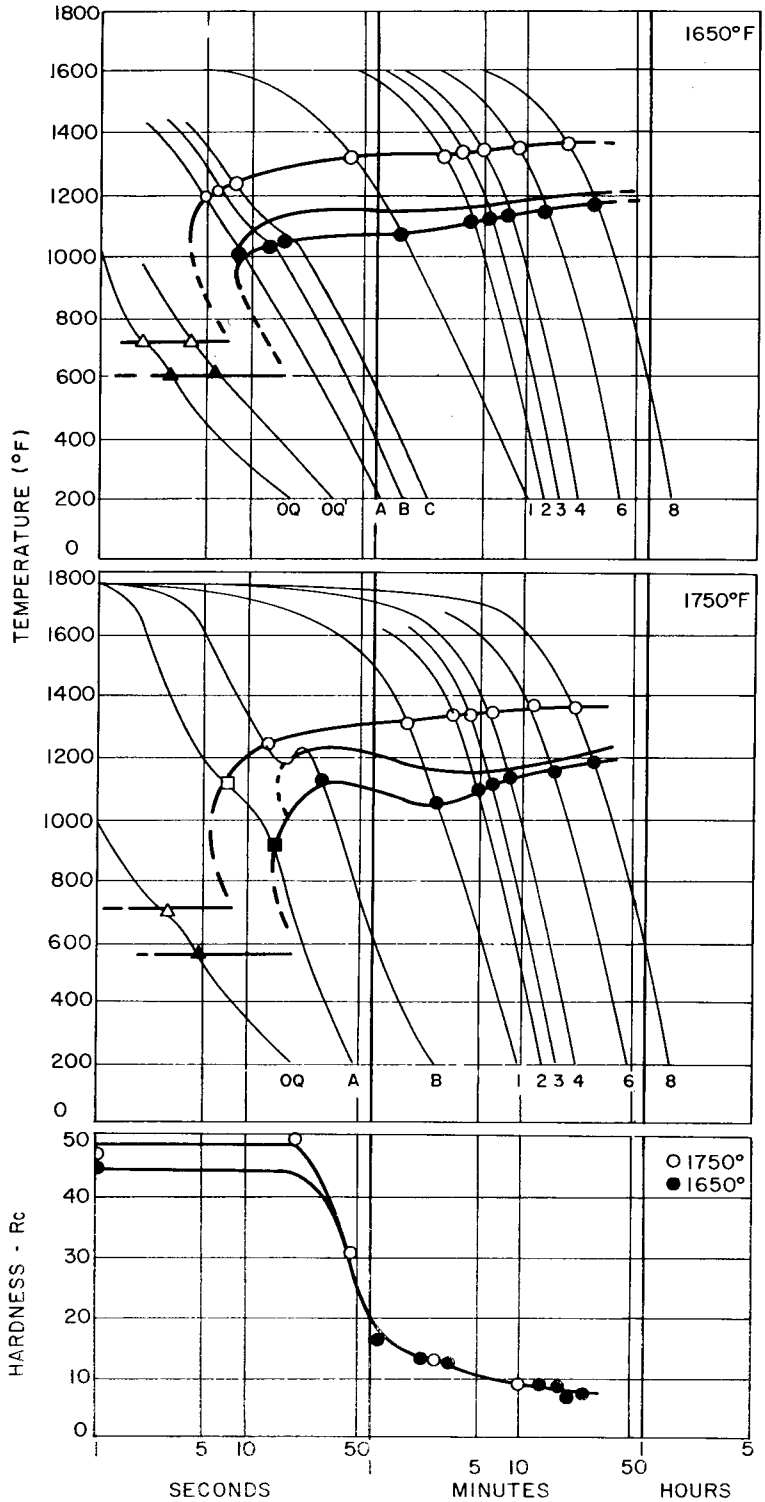


Fig. 1 — The cooling-transformation diagrams and hardness values for the control steel (Mark F) austenitized at 1650 and 1750°F

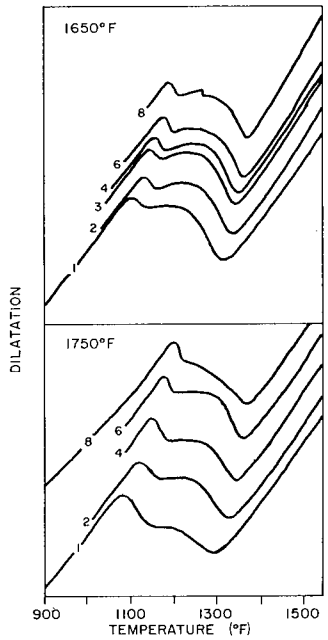
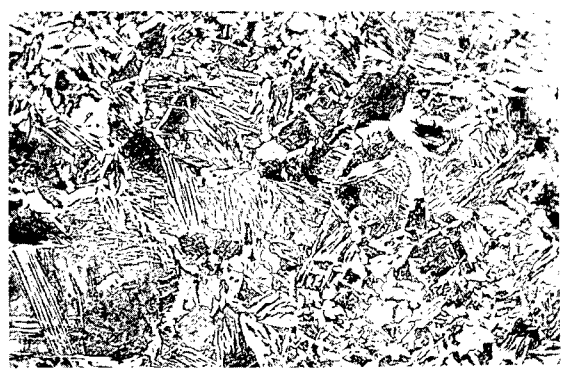
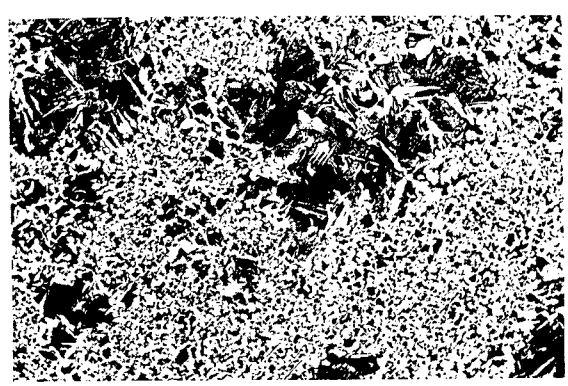


Fig. 2 — The dilatation-temperature curves for the control steel (Mark F) austenitized at 1650 and 1750°F

(a)



(b)



(c)

Fig. 3 — The microstructures of the control steel (Mark F) austenitized at 1750°F. (a) Oil quenched: martensite formation; (b) cooling rate A (cooled to 200°F in 50 sec): upper bainite and fine pearlite formation; and (c) cooling rate 2 (cooled to 200°F in 13 min): ferrite and pearlite formation (note mixed grain size). (Original magnification 800X for (a) and (b), 100X for (c). Reduction in printing approx. 45%.)

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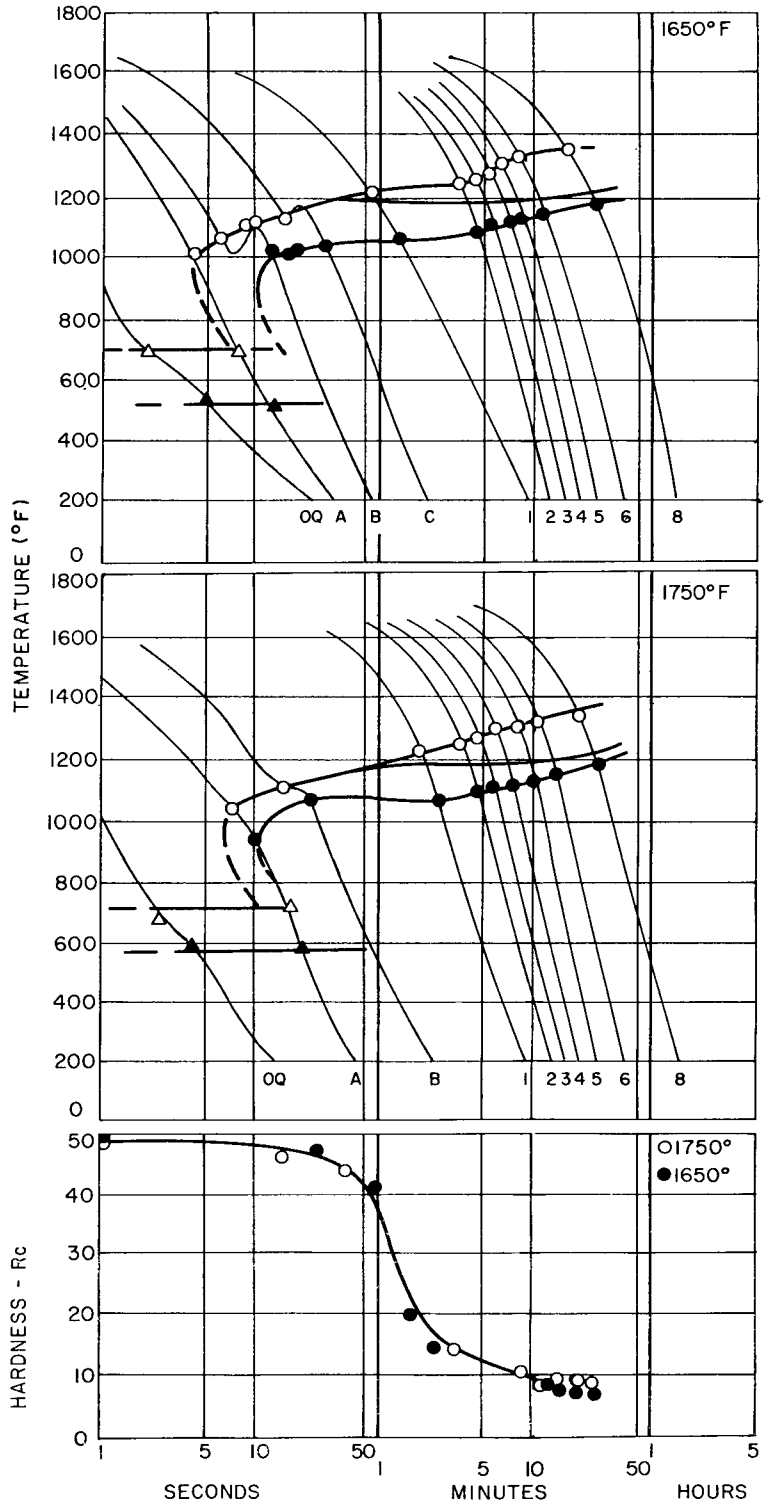

Fig. 4 — The cooling-transformation diagrams and hardness values for the control steel (Mark OU) austenitized at 1650 and 1750°F

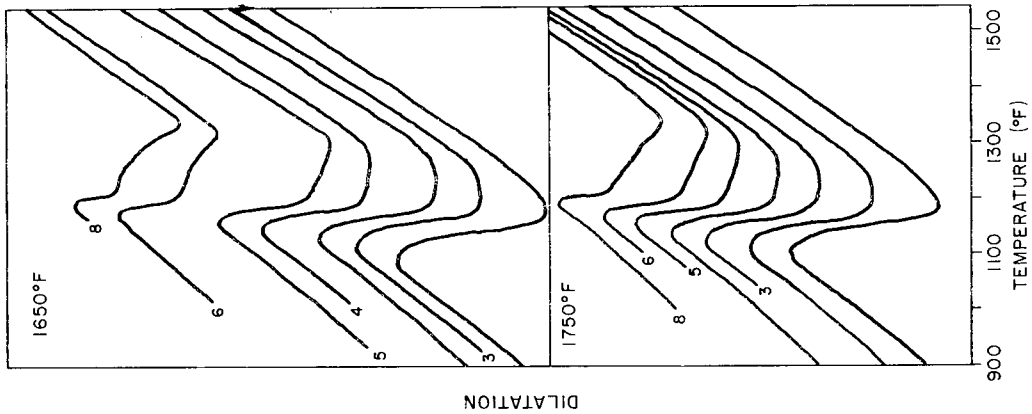

Fig. 5 — The dilatation-temperature curves for the control steel (Mark OU) austenitized at 1650 and 1750°F

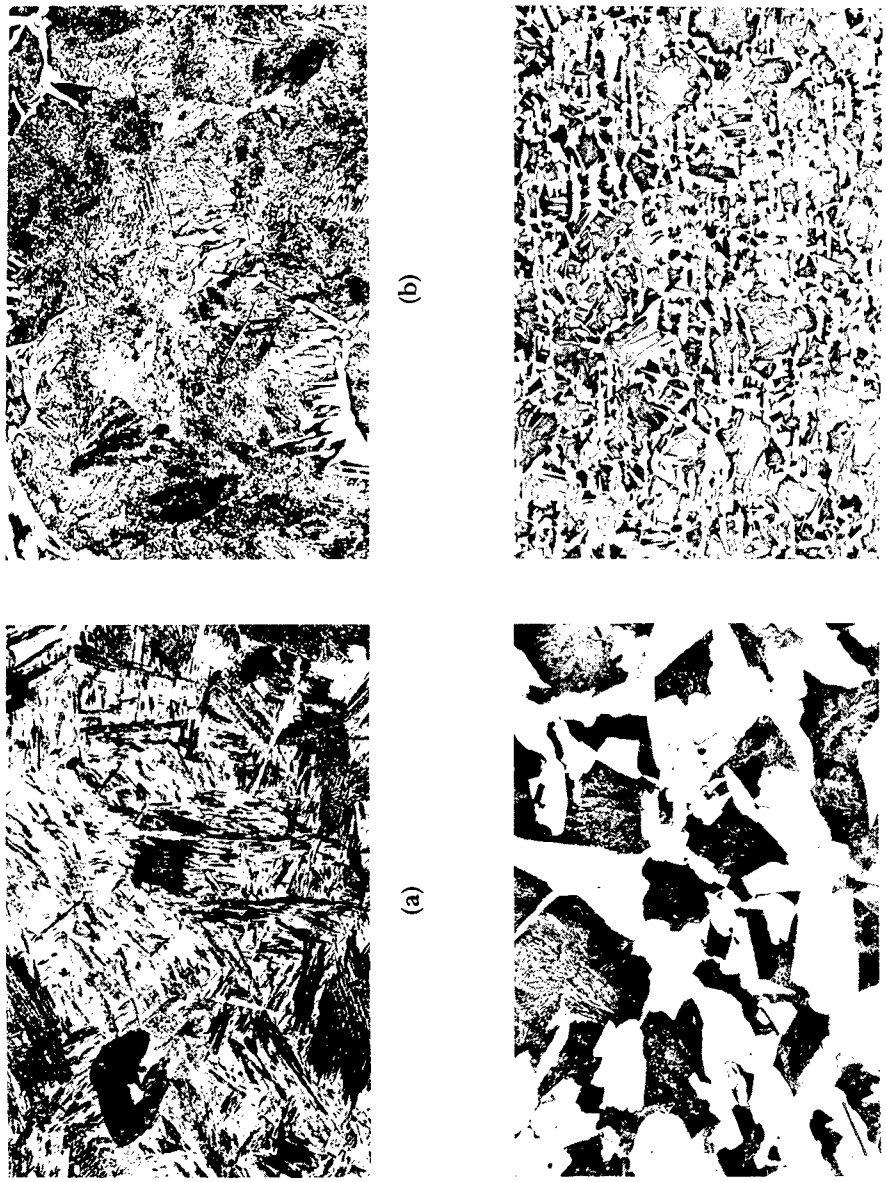

Fig. 6 — The microstructures of the control steel (Mark OU) austenitized at 1650 and 1750°F. (a) Cooling rate A (cooled to 200°F in 45 sec from 1750°F): fine pearlite and ferrite formation in a matrix of martensite; (b) cooling rate C (cooled to 200°F in 3 min from 1650°F): fine pearlite and ferrite formation; (c) cooling rate 6 (cooled to 200°F in 40 min from 1650°F): ferrite and pearlite formation; and (d) cooling rate 6 (cooled to 200°F in 40 min from 1650°F): ferrite and pearlite formation. (Original magnification 800X for (a) and (b), 100X for (c), and 600X for (d). Reduction in printing approx. 50%.)

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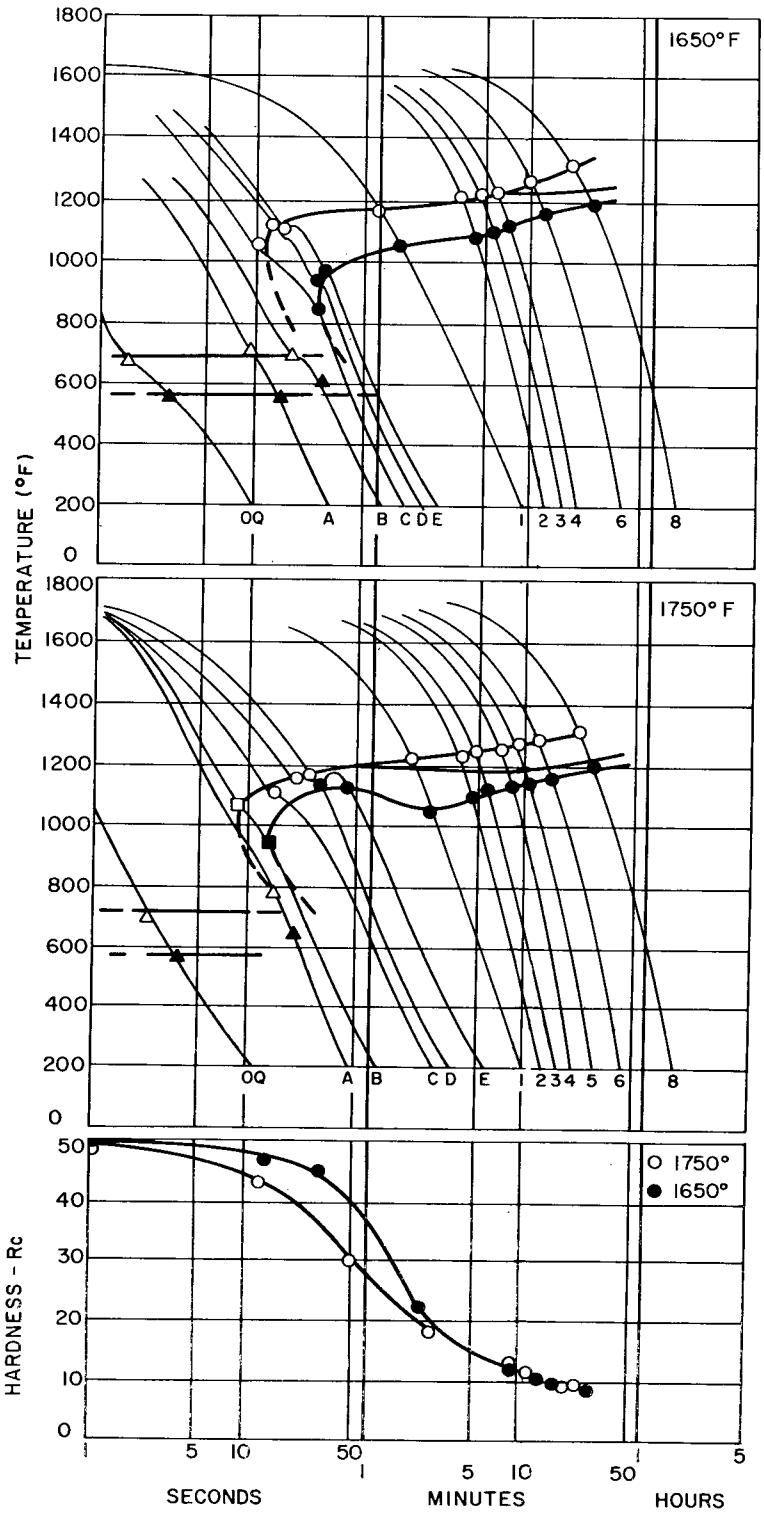

Fig. 7 — The cooling-transformation diagrams and hardness values for the 0.06-percent U steel (Mark .06U) austenitized at 1650 and 1750°F

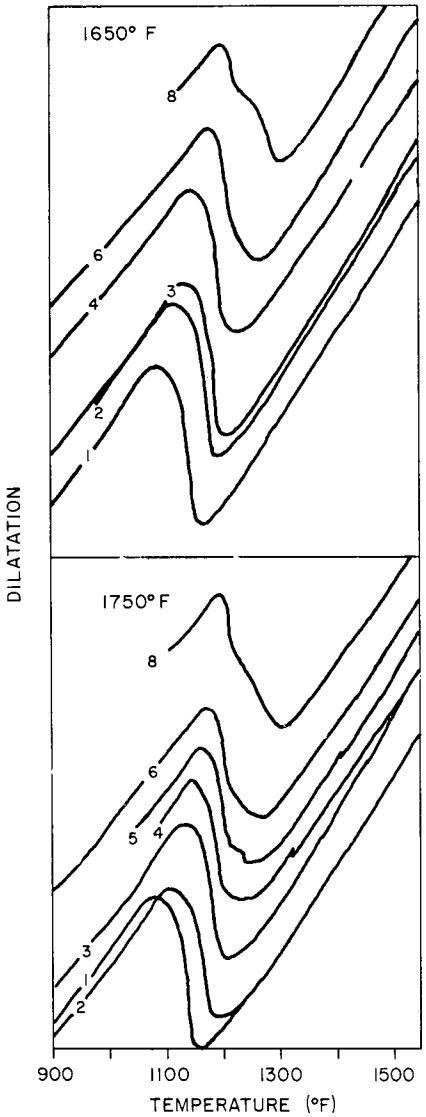

Fig. 8 — The dilatation-temperature curves for the 0.06-percent U steel (Mark .06U) austenitized at 1650 and 1750°F

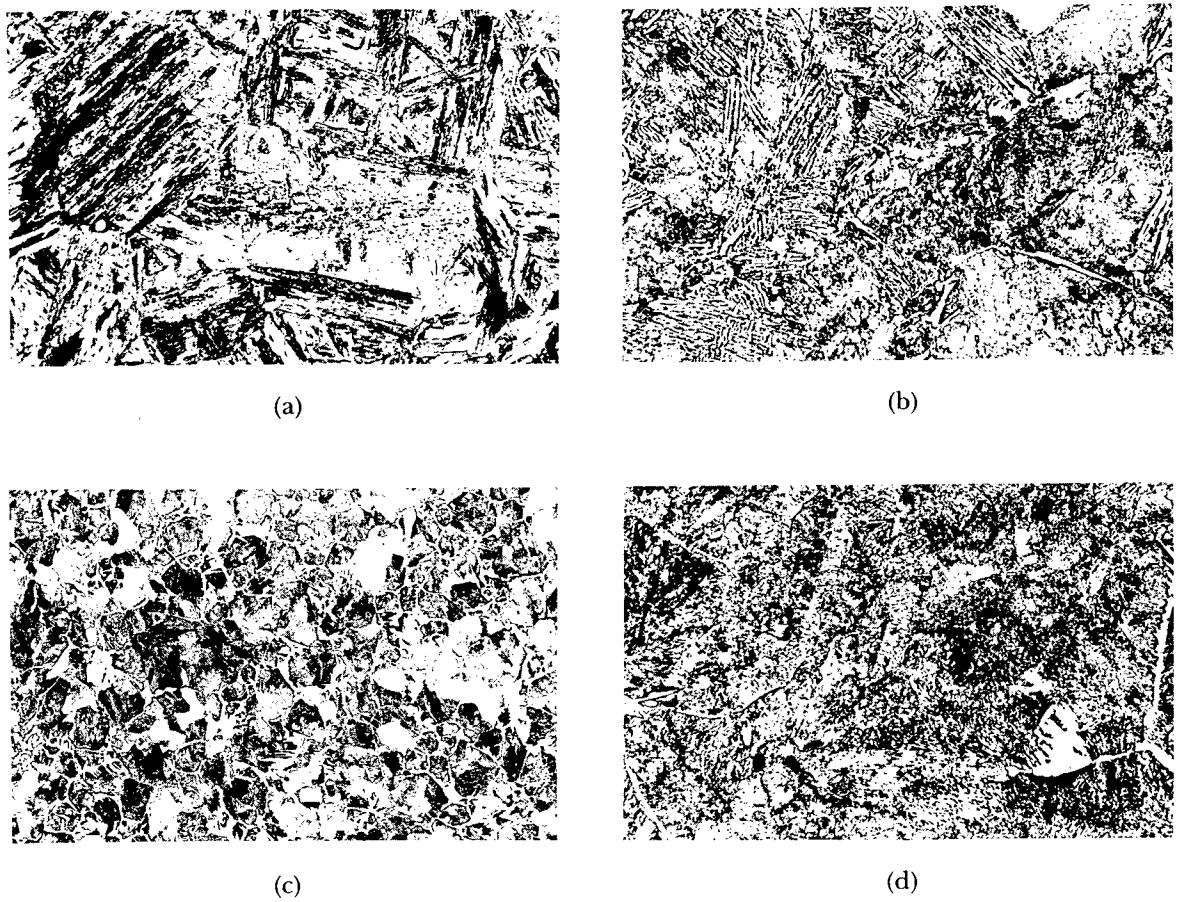

Fig. 9 — The microstructures of the 0.06-percent U steel (Mark .06U) austenitized at 1750°F. (a) Cooling rate A (cooled to 200°F in 45 sec): coarse martensite formation; (b) cooling rate B (cooled to 200°F in 70 sec): upper bainite and fine pearlite formation; (c) cooling rate E (cooled to 200°F in 5-1/2 min): grain boundary ferrite and fine pearlite formation; and (d) cooling rate 2 (cooled to 200°F in 14 min): grain boundary ferrite and fine pearlite formation. (Original magnification 800X for (a), (b), and (c), and 100X for (d). Reduction in printing approx. 50%.)

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The CT diagrams for the 1.1-percent U steel are presented in Fig. 10, and the dilatation-temperature curves are given in Fig. 11. For this steel, martensite is formed on drastic quenching. As the cooling rate is reduced, bainite is formed (Fig. 12a). At a slower cooling rate, a coarse bainite structure is developed (Fig. 12b), which subsequently gives way to an angular, nearly Widmanstätten, ferrite structure. With further reduction in cooling rate this Widmanstätten ferrite coarsens, and the austenite matrix transforms to pearlite (Fig. 12c). The structure formed at the minimum cooling rates consists of equiaxed ferrite and pearlite colonies (Fig. 12d), in which are dispersed stringers of a third microconstituent. Reexamination of the microstructures for the faster cooling rates revealed that this latter microconstituent regularly appears, but no effort has been made to establish the details of the appearance of this product.

DISCUSSION

A quenched section of material will cool at a maximum rate at the quenching-medium/material interface. As the distance from the quenching-medium/material interface is increased, the cooling rate will continuously decrease to a minimum value determined by the dimensions of the section. The microstructures developed in the section, to a first approximation, will vary with the cooling rate. Conversely, if the microstructures developed in a quenched section are known for a steel with known cooling-transformation characteristics, the cooling conditions at locations of interest can be estimated to fall within certain intervals. To assist in the interpretation of microstructures formed in the present steels when heat treated in plate section, a correlated series of microstructures for the three comparative steels are presented in Figs. 13-15. In each series the fully quenched martensitic structure is presented both as formed during water and during oil quenching; the microstructural changes accompanying changes in quenching bath are readily evident. Typical changes in the microstructures with the appearance of high-temperature transformation products are next presented and identified. The structures corresponding to nominally slow-cooled structures are then presented for the fastest cooling rates at which they appear. These structures are modified somewhat at the lower cooling rates but persist in recognizable form.

It is pointed out that somewhat objectionable composition variations exist in the present laboratory series of steels. This question in its several ramifications has not been examined at length, but it is deemed important in the ultimate establishment of the properties of these steels. The variations of concern are suggested by the microstructures in Fig. 16 for the 1.1-percent U steel. The microstructure presented is a matrix of ferrite with a probable dispersion of Fe_2U. There appears to be no carbide in the structure. This structure is considered atypical and it was infrequently encountered. The impact specimens which served as the material source for the present study were selected to give typical microstructures, and these have been depicted in the foregoing figures. Figure 16 indicates well the precipitate distribution in the 1.1-percent U steel.

The effect of a given alloy addition on the microstructure of a heat-treated steel is usually projected as being relatively established by the microstructures developed in plain-carbon steels. In reality this assumption holds for a number of the common alloy additions, but definitely does not hold for others. Of particular interest in this latter respect are the pearlite structures formed in steels alloyed with molybdenum and vanadium. For example, in molybdenum steels pearlite structures are very difficult to obtain, and well-formed lamellar pearlites are probably not possible. Steels containing vanadium have not been studied intensively for microstructural variations in the pearlite range, but a steel containing Cr and V will regularly transform in the pearlite interval without the formation of lamellar pearlite. It is probably correct to say that, in the past, the development of pearlite structures was considered to be contingent on the manner in which carbon diffuses at the reaction interface, and this has been projected as essentially entailing a lamellar-or lath-shaped pearlitic structure. It is important to note that a restriction of this kind is not, in general, imposed on the structure of eutectics, where considerations of the relative volumes of the participating phases have been considered to be a significant factor establishing the eutectic microstructure. It would seem probable that this latter factor would also affect the structure of the eutectoid transformations in steels.

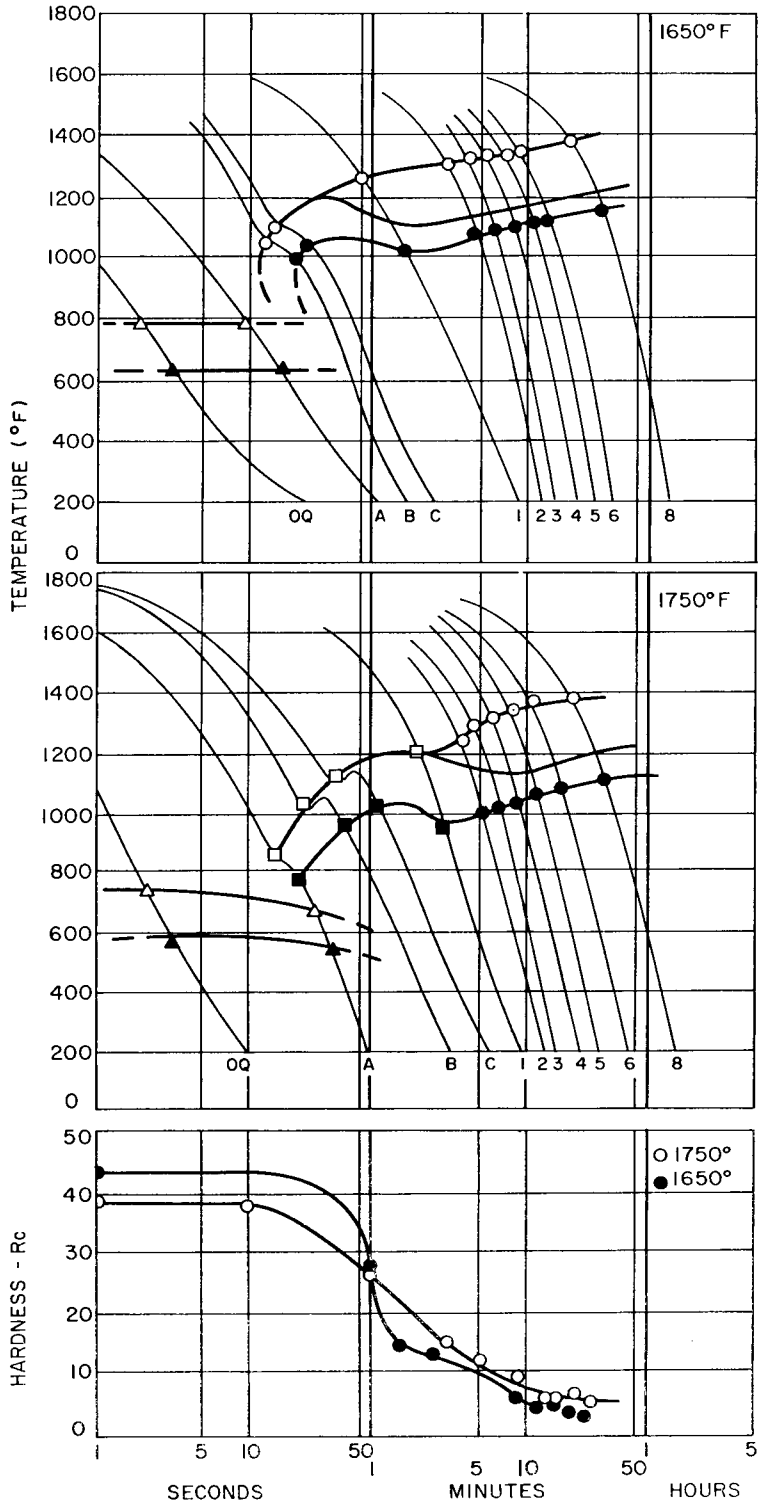

Fig. 10 — The cooling-transformation diagrams and hardness values for the 1.1-percent U steel (Mark 1.1U) austenitized at 1650 and 1750°F

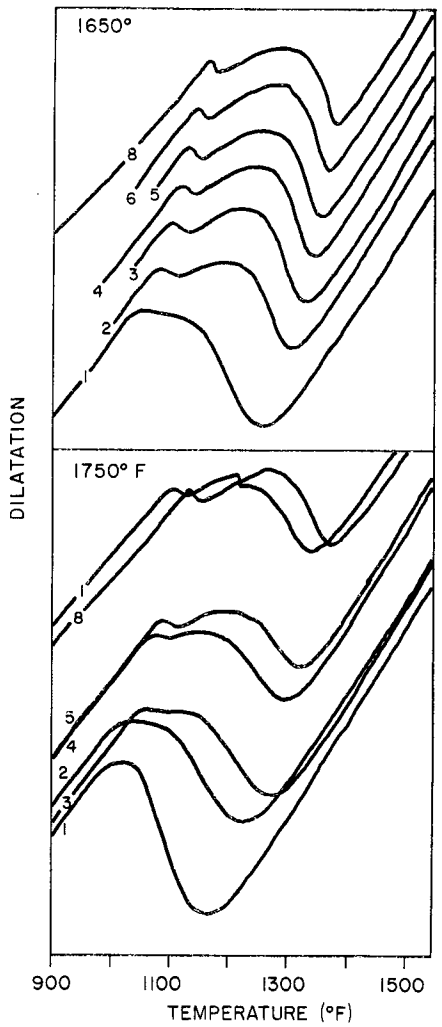

Fig. 11 – The dilatation-temperature curves for the 1.1-percent U steel (Mark 1.1U) austenitized at 1650 and 1750°F

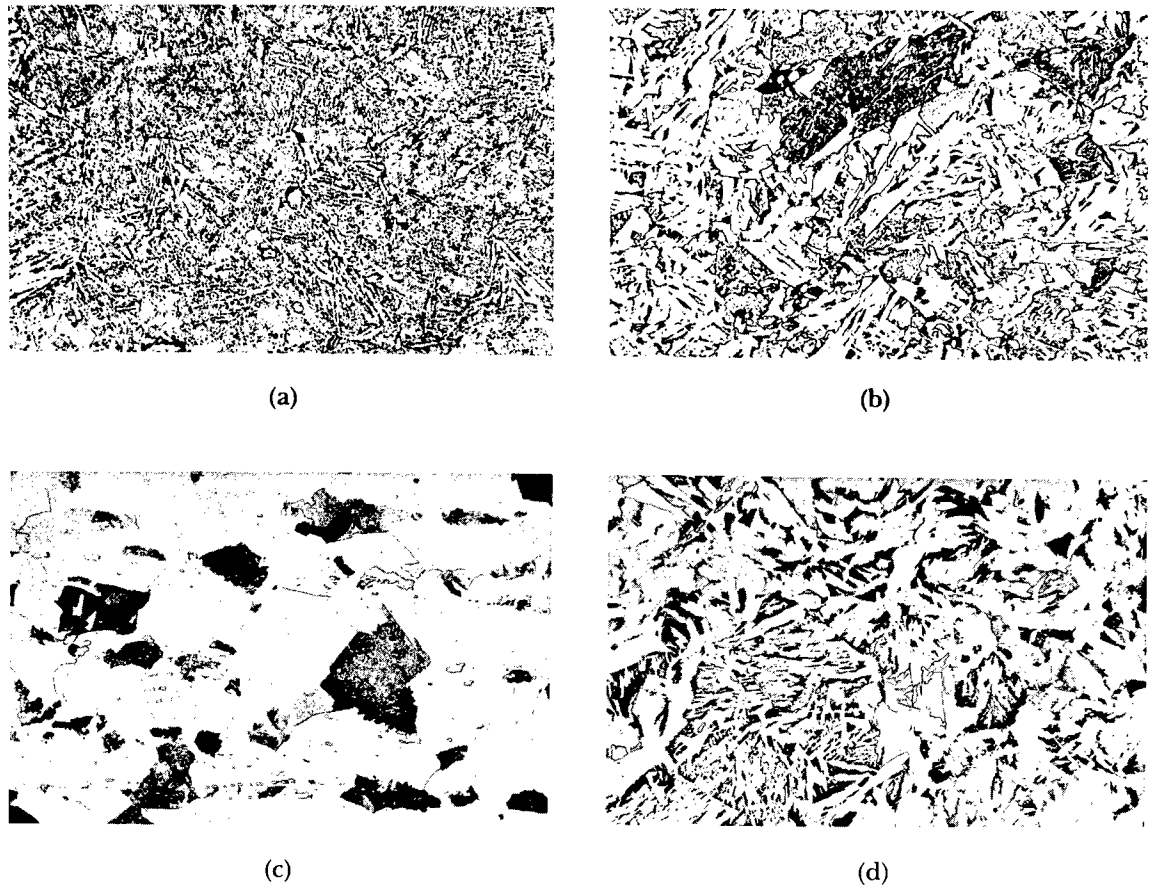

Fig. 12 – The microstructures of the 1.1-percent U steel (Mark 1.1U) austenitized at 1750°F. (a) Cooling rate A (cooled to 200°F in 1 min): bainite formation; (b) cooling rate B (cooled to 200°F in 3-1/2 min): coarse bainite formation; (c) cooling rate 1 (cooled to 200°F in 10 min): Widmanstätten ferrite and pearlite formation; and (d) cooling rate 8 (cooled to 200°F in 1-1/2 hr): equiaxed ferrite and pearlite colonies. (Original magnification 800X for (a) and (b), and 600X for (c) and (d). Reduction in printing approx. 50%.)

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Fig. 13 — The microstructures of the control steel (Mark OU) austenitized at 1650°F. (a) Water quenched: martensite formation; (b) oil quenched: martensite formation; (c) cooling rate A (cooled to 200°F in 35 sec): acicular and grain boundary ferrite, fine pearlite, and martensite formation; (d) cooling rate B (cooled to 200°F in 55 sec): Widmanstätten ferrite and fine pearlite formation; (e) cooling rate C (cooled to 200°F in 2 min): Widmanstätten ferrite, and fine and coarse pearlite formation; and (f) cooling rate 1 (cooled to 200°F in 10 min): Widmanstätten and massive ferrite, and coarse pearlite formation. (Original magnification 800X for all photos. Reduction in printing approx. 50%.)

Fig. 14 — The microstructures of the 0.06-percent U steel (Mark .06U) austenitized at 1650°F. (a) Water quenched: martensite formation; (b) oil quenched: martensite formation; (c) cooling rate A (cooled to 200°F in 32 sec): martensite formation; (d) cooling rate C (cooled to 200°F in 1-1/2 min): acicular ferrite and fine pearlite formation; (e) cooling rate E (cooled to 200°F in 2-1/2 min): Widmanstätten and massive ferrite, and fine pearlite formation; and (f) cooling rate 1 (cooled to 200°F in 9 min): Widmanstätten and massive ferrite, and coarse pearlite formation. (Original magnification 800X for all photos. Reduction in printing approx. 50%.)

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Fig. 15 — The microstructure of the 1.1-percent U steel (Mark 1.1U) austenitized at 1650°F. (a) Water quenched: martensite formation; (b) oil quenched: martensite formation; (c) cooling rate A (cooled to 200°F in 70 sec): martensite formation; (d) cooling rate B (cooled to 200°F in 100 sec): Widmanstätten ferrite formation; (e) cooling rate C (cooled to 200°F in 2-1/2 min): massive angular ferrite formation; and (f) cooling rate 1 (cooled to 200°F in 9 min): equiaxed ferrite and fine pearlite formation. (Original magnification 800X for all photos. Reduction in printing approx. 50%.)

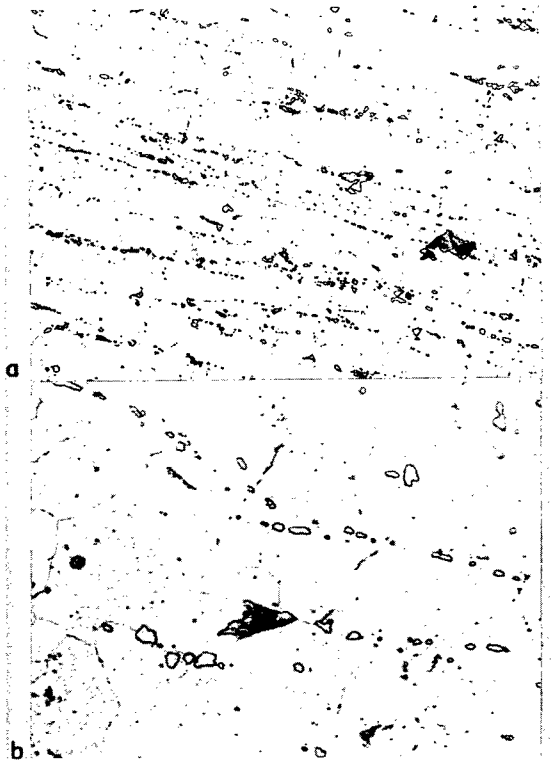

Fig. 16 — A microstructure showing carbon depletion in the 1.1-percent U steel (Mark 1.1U) austenitized at 1650°F and cooled to 200°F in 30 min (cooling rate 5). The precipitate structure is probably Fe_2U. (Original magnification 200X for (a) and 800X for (b). Reduction in printing approx. 65%.)

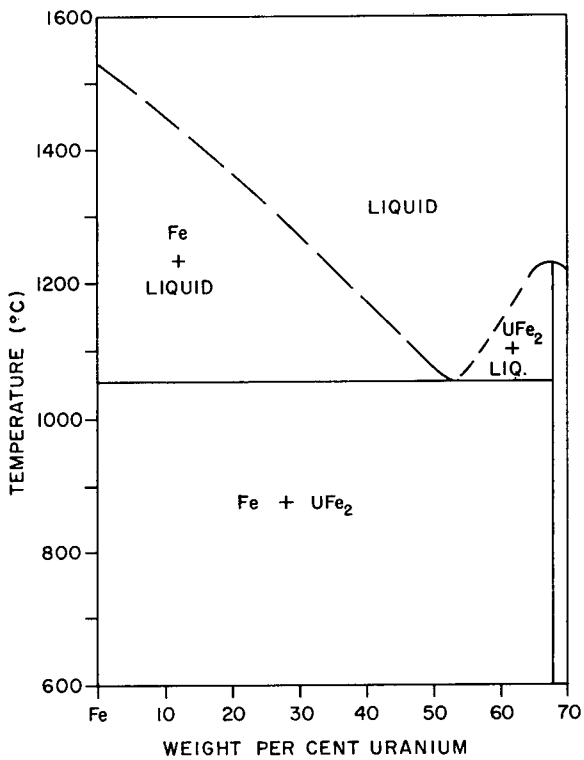

Fig. 17 — The phase diagram for Fe-U alloys, after Grogan (1)

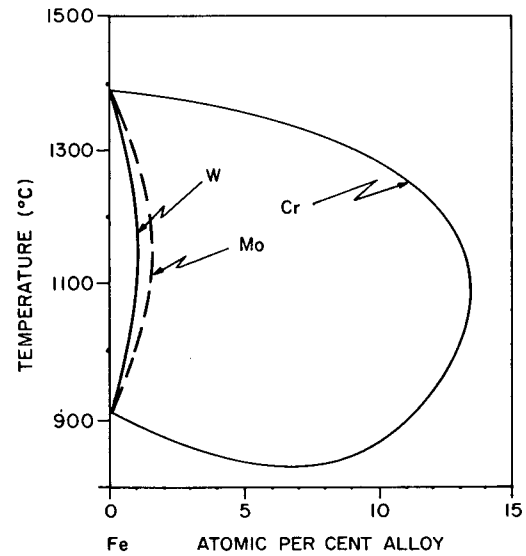

Fig. 18 — The γ-phase fields for iron alloyed with Cr, Mo, and W (6)

In this respect the U-bearing steels are particularly interesting because U is only mildly soluble in iron, as the phase diagram of Fig. 17 indicates. This diagram, while not directed at establishing the iron-rich portion of the Fe-U system in detail, indicates that U is soluble only to a very limited degree in α-iron. The solubility of U in γ-iron must also be restricted, as indicated by the relative γ-phase fields (6) for the VIa subgroup elements with iron in Fig. 18. However, no difficulty is experienced in austenitizing the U-bearing steels to a (nominally) fully austenitic condition. For the austenitizing cycles employed, the 1.1-percent U alloy would seem to be slightly into the austenite-UFe_2 phase field, and this might be important for the development of mechanical properties in this alloy. The volume of the projected UFe_2 phase is small, however, and should not seriously affect austenite decomposition on quenching. However, for a more satisfactory understanding of the microstructural changes that have resulted from the presence of U in the quenched steels, it is desirable that more detailed information of the Fe-C-U phase equilibria be available. At the present time it would appear that a pseudobinary eutectoid forms in the U-bearing steels, but this proposal is only tentatively advanced and, for satisfactory resolution, must await the investigation of additional Fe-C-U compositions.

The introduction of uranium into a heat-treated steel may produce relatively profound microstructural changes in the steel on quenching. For the steels studied in this investigation, these microstructural changes are accomplished without major modification of the depth of hardenability, as indicated in Fig. 19. Here the interesting situation develops in which a high-temperature reaction is suppressed, leading to the development of soft low-temperature products. This then results, for practical purposes, in a loss in hardenability.

SUMMARY

The cooling transformations in four steels have been studied for alteration due to the effect of minor additions of uranium (U). From the combined analysis of thermal and dilatation curves, hardness, and metallographic structures, it has been concluded that:

a. The hardenabilities of the steels investigated are little affected by the uranium additions studied.

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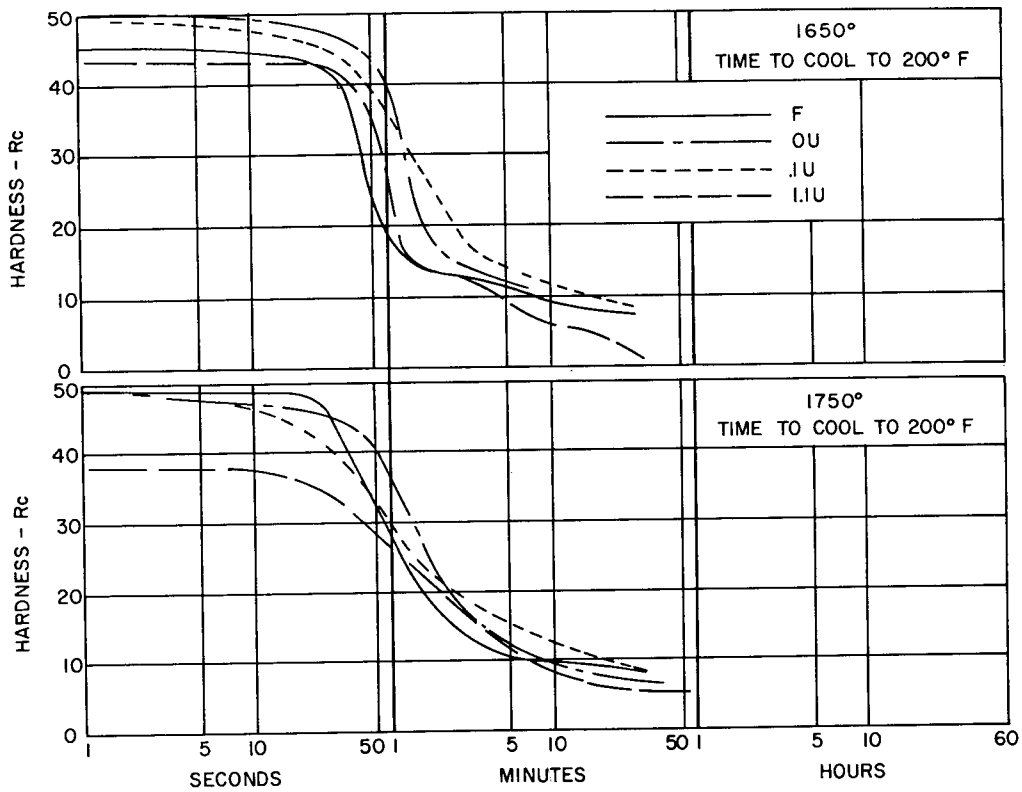

Fig. 19 — The hardenability curves determined from CT specimens for the steels studied: (a) austenitized at 1650°F, and (b) austenitized at 1750°F

b. Despite the insensitiveness of hardenability to the presence of uranium, the cooling transformations are significantly modified by even the minimum level of uranium addition employed. This appears to result from the marked effect that uranium has on the eutectoid composition, which is probably in the interval of 0.06 to 0.1 percent U for the 0.30-percent C steels studied.

c. Austenitizing at 1650 or at 1750°F leads to further changes in the cooling transformations in the respective steels, but again the hardenability is but little affected.

d. Since austenitizing at 1750°F leads to mixed grain structures for the steels, this temperature is deemed too high for use because of the deterioration in fracture properties that would result from the resultant coarsened structure.

e. Minor additions of uranium to A212-B steel, by modification of cooling transformations, may alter the radiation sensitivity of this steel if microstructure is an influential factor in determining irradiation response.

The influence of uranium on the irradiation behavior of structural steels is being investigated as a separate experimental program. Preliminary results of this investigation will be reported in the near future.

REFERENCES

1. Grogan, J.D., "The Uranium-Iron System," *J. Inst. Metals* **77**:571 (1950)
2. Bain, E.C., "Functions of the Alloying Elements in Steel," Cleveland; *ASM*, 1939
3. Klier, E.P, and Lyman, T., "The Bainite Reaction in Hypoeutectoid Steels," *Trans. AIME* **158**:394 (1944)
4. Klier, E.P., and Yeh, T.H., "The Decomposition of Austenite in 4340 Steel During Cooling," *Trans. ASM* **53**:75 (1961)
5. Klier, E.P., and Jellison, J., "The Effect of Austenitizing Temperature on the Cooling Transformations in 43XX Steels," *Trans. Quart. ASM* **57(No. 1)**:186 (1964)
6. Hansen, M., "Constitution of Binary Alloys," New York: McGraw-Hill, 2nd ed., pp. 527, 669, and 734, 1958

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13. ABSTRACT

The continuous cooling transformations of three laboratory heats, containing 0.0.06, and 1.1 percent natural uranium (U), and of a uranium-free commercial heat, following austenitizing at 1650 and 1750°F, have been investigated. The melts were prepared to the nominal composition for ASTM A212-B steel. Hardness measurements, as well as metallographic examinations, of the transformed structures were included in this study.

The two uranium-free steels yielded very similar cooling-transformation diagrams and exhibited essentially equivalent hardenability; however, the hardenability of the uranium-free commercial heat was limited by ferrite and upper bainite formation, while that of the laboratory heat was restricted by pearlite formation.

Uranium additions of 0.06 and 1.1 percent were not found to have any significant effect upon hardenability although, unlike the uranium-free laboratory heat, the hardenability of these steels was limited by upper bainite formation. Suppression of the proeutectoid ferrite reaction at intermediate cooling rates was observed to increase with uranium content.

Metallographic examinations of the 1.1-percent U steel revealed a stringer dispersion of a microconstituent, possibly Fe_2U, in all structures produced over the range of cooling conditions employed. The volume of this phase was small, however, and thus is not believed to have a serious effect on austenite decomposition when quenching.

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