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METALLOGRAPHIC STUDY OF THE FORMATION OF AUSTENITE FROM AGGREGATES OF FERRITE AND CEMENTITE IN AN IRON-CARBON ALLOY OF 0.5 PERCENT CARBON

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ABSTRACT

The formation of austenite on heating aggregates of ferrite and cementite in a high-purity alloy of iron and carbon (0.50 percent carbon) is described. In fine pearlite, austenite was preferentially nucleated at the interfaces of ferrite and carbide at the boundaries of pearlite colonies and proeutectoid ferrite or at the boundaries between pearlite colonies, although it occasionally formed within the colonies. In spheroidized structures, nucleation occurred at ferrite-carbide interfaces at the cementite network or at isolated cementite particles. Austenite formed at numerous interfaces, so that in the initial stages it was always *fine-grained.* However, if the rate of heating is slow, rapid grain growth takes place in the Ac_1-Ac_3 temperature range. The predominant factor in establishing the austenite grain size in this alloy was the rate of growth and not the rate of nucleation.

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I. INTRODUCTION

The mechanism of the formation of austenite from pearlite has been studied by various investigators, and it is now generally recognized that austenite forms from pearlite by nucleation and growth. These studies, however, have been made principally on plain carbon steels. It should be of interest to study the formation of austenite in iron-carbon alloys, in which any possible effects due to the presence of extraneous elements would be kept to a minimum. Since iron-carbon alloys of high purity are known to be relatively coarse-grained, it might be expected that transformations in such alloys could be more easily followed than in steels.

In previous studies [1][1] of the influence of certain factors on austenite grain size [1, 2] and its accompanying effect on hardenability [3],

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[1] Figures in brackets indicate the literature references at the end of this paper.

some observations were made on the mechanism of the formation of austenite in high-purity alloys of iron and carbon. The present report describes this mechanism in an alloy containing 0.50 percent of carbon with initial structures of either fine pearlite (sorbite) or spheroidized cementite.

II. PREVIOUS INVESTIGATIONS

Grossmann [4, 5] studied the formation of austenite grains and the manner in which they coarsen in low-carbon steels. He briefly summarized the mechanism as follows: "When, upon heating, the steel reaches the temperature at which it begins to transform to austenite, the first very minute austenite crystals form within a pearlite island or in the boundaries between ferrite grains. These small austenite grains then grow across the pearlite islands and across the ferrite grains, until they meet other austenite grains which have grown from other nuclei. When all the austenite grains have thus met, so that the whole piece consists of austenite, it is clear that a certain set of grain-sizes will have been established." He pointed out that these initial austenite grains, usually in the range of American Society for Testing Materials numbers 5 to 8, do not grow even if the steel is heated for considerable periods of time just above the transformation temperature or to somewhat higher temperatures.

The strucutral changes occurring in steel on heating have been described by Carpenter and Robertson [6]. In each area of pearlite in hypoeutectoid steel, austenite begins to form at several points on the boundaries between pearlite and ferrite. The austenite spreads as the change proceeds, but the way in which this takes place is not related to the structure of the pearlite. At all times during the change the austenite areas have an irregular shape, and their outlines contain reentrant curves. In all steels, whatever their previous treatment, the austenite grains existing just above the critical range are small.

From a study made with carbon steels ranging in carbon from 0.45 to 1 percent, Baeyertz [7] reported that the austenite grains formed in entirely different ways in the same steel, depending on whether the prior structure was pearlite or martensite. In pearlite, nucleation of austenite grains occurred at the boundaries of the ferrite-cementite lamellas within pearlite colonies and not in the ferrite grain boundaries. The austenite grains grew along the pearlite lamellas, so that in the absence of coarsening, the structure contained elongated and irregularly shaped grains which took their conformation from the pearlite lamellas in which they formed. Austenite grains did not readily grow across the ferrite grain boundaries which separated the pearlite colonies; in the absence of coarsening, therefore, the austenite grain size at the end of the transformation was equal to or less than that of the prior pearlite colony. In spheroidized structures, the formation of austenite began in the grain boundary of the prior austenite. The nuclei for austenite formed at the ferrite-cementite phase boundaries around those cementite particles which were in the ferrite grain boundaries. With martensite, spheroidization occurred very readily below the Ac_1. The austenite produced just above the Ac_1 was formed not from martensite proper but from a spheroidized structure.

Mehl [8] reported that the rate of austenitizing was the greater the finer the spacing of the pearlite and that fine-grained steel (aluminum-killed) austenitized more slowly than coarse-grained steel. No detectible difference was found in the rates of nucleation for austenitizing of any of the specimens employed. At that time, Mehl was inclined to believe that the rate of growth was the important variable in austenitizing, and not the rate of nucleation.

The formation of austenite in plain carbon steels was also investigated by Hultgren [9] and by Shapiro [10]. Hultgren discussed the factors that caused the Ac_1 to occur over a range of temperatures, and he pointed out the need of similar experiments with high-purity iron-carbon alloys. Shapiro presented photomicrographs showing the mechanism of the alpha to gamma transformation in steels with different structures consisting of either pearlite, troostite, or spheroidized cementite.

III. EXPERIMENTAL PROCEDURE

Specimens of a high-purity alloy of iron and carbon (less than 0.031 percent of identifiable impurities) containing 0.50 percent of carbon were heated in such a manner that a portion passed through the Ac_1 transformation, whereas the remainder was below this temperature. The austenite thus formed was then decomposed into martensite or nodular troostite (fine pearlite) by rapid quenching. The specimens (approximately $\frac{1}{16}$ by $\frac{1}{10}$ by $\frac{1}{4}$ inch) had initial structures of either fine pearlite (sorbite) and ferrite, or spheroidized cementite. Each specimen was heated within a Nichrome coil in vacuum at a selected rate to the desired temperature, held for a predetermined period and then quenched directly in gas (helium) in a manner similar to that previously described [3]. The quenched specimens were prepared by the usual means for metallographic study. The structural features of the changes are shown in the accompanying photomicrographs.

IV. DISCUSSION

In a study of the structural changes accompanying the heating of a hypoeutectoid iron-carbon alloy, it appears pertinent to examine the initial transformation of austenite from different aggregates of ferrite and carbide and to follow progressively the nucleation and growth of these austenite grains with time and with temperature.

Attention should be directed to the fact that the carbon content of pearlite in a hypoeutectoid steel may be less than that of the eutectoid. In order that the composition of pearlite in such a steel may correspond to that of the eutectoid, relatively slow cooling from above the critical range is necessary. If cooling is hastened, less free ferrite is precipitated, and hence the carbon content of the pearlite is less than that of the eutectoid. The more rapid the cooling, the more pronounced is this effect until the structure consists entirely of pearlite, which will then have a carbon content corresponding to that of the steel. The fine pearlite in the iron-carbon alloy used in the present study was produced by relatively rapid cooling. The amount of proeutectoid ferrite in this initial structure was small, and it was estimated from the microstructure that the carbon content of the pearlite possibly was as low as 0.55 percent, and certainly not more than 0.6 percent.

1. FORMATION OF AUSTENITE FROM FINE PEARLITE

The beginning of the formation of austenite from fine, carbon-poor pearlite is illustrated in figure 1. This specimen was heated sufficiently rapidly to the Ac_1 temperature to retain some of the cementite plates in the pearlite. At the Ac_1 temperature, austenite began to form at the interfaces of ferrite and cementite, as shown by the presence of troostite (a decomposition product of austenite) obtained by quenching. Evidently the small area of troostite shown at the lower left of the photomicrograph (fig. 1, *A*) was originally austenite that was nucleated at the point of contact of lamellar carbide with proeutectoid or free ferrite, whereas the minute area of troostite shown near the center of the photomicrograph was austenite that was formed in the region of a boundary common to two colonies of pearlite. Although austenite appeared to be preferentially nucleated in these regions, it occasionally originated within a pearlite colony (fig. 1, *B*).

With increase in time at the Ac_1 temperature, the areas of austenite increased in size and additional nuclei became active in different regions of pearlite, as illustrated in figue 2, *A*. As the specimen was maintained at this temperature, new austenite grains continued to form and grow (fig. 2, *B*) and the already existing grains increased in size, usually preferentially along the cementite lamellas (fig. 3, *A*), until all the pearlite was consumed and only two phases remained, ferrite and austenite (transformed to martensite and troostite) containing eutectoid carbon (fig. 3, *B*). With increase of temperature above that of the Ac_1 transformation, the percentage of austenite increased, and its carbon content decreased as ferrite was absorbed. At a temperature somewhat below the Ac_3 transformation there remained only a small percentage of ferrite (fig. 4, *A*); at the Ac_3 temperature the absorption of the ferrite was completed and only one phase remained—austenite (transformed to martensite on quenching) with an average carbon content of 0.50 percent (fig. 4, *B*). Although the austenite grains can grow with increase in temperature above Ac_3, no further structural changes take place until melting begins.

Austenite is nucleated at a cementite-ferrite interface. In pearlite (plus ferrite) such interfaces may be located (1) at the boundary between a pearlite area and proeutectoid ferrite, (2) at the common boundary of two or more pearlite colonies, and (3) within a pearlite colony.

The formation of austenite from lamellar pearlite is illustrated by figure 5. This sketch shows the nucleation of austenite at ferrite-cementite interfaces within a pearlite colony, but the initial formation of austenite and its growth in fine pearlite is believed to be similar, regardless of where nucleation occurs.

Figure 5, *A*, illustrates an individual colony of pearlite having alternate lamellas of cementite (Fe_3C) and ferrite (α-iron). For comparison with the iron-carbon alloy, it is assumed that the carbon content of this entire colony is considerably less than that of the eutectoid, i. e., this pearlite is also carbon-poor. If this *entire* area of pearlite should transform to austenite at the Ac_1 temperature, then one of two possibilities must exist. Either the austenite must have a carbon content corresponding to that of the pearlite (less than eutectoid) or, if the carbon content of the austenite approximates that of the eutectoid, then free ferrite must exist in conjunction with the austenite. Microscopic evidence supports the latter possibility.

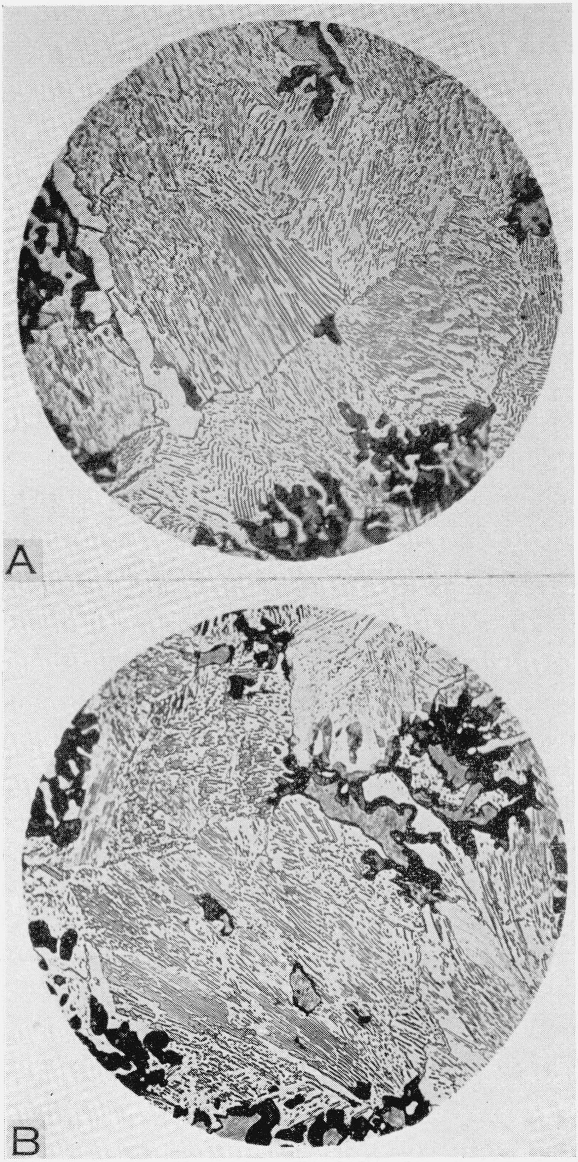

FIGURE 1.—*Nucleation of austenite from fine pearlite at the Ac_1 temperature.*

A, The small area of troostite (dark) (7 o'clock position) was originally austenite nucleated at the point of contact of lamellar cementite with proeutectoid ferrite (white). The small area of troostite near the center was originally austenite nucleated at the boundary common to two colonies of pearlite.

B, The several small areas (martensite (gray) and troostite) in the lower central portion of the photomicrograph were originally austenite nucleated within a pearlite colony. Note tendency of the austenite to grow in the direction of the pearlite lamellas.

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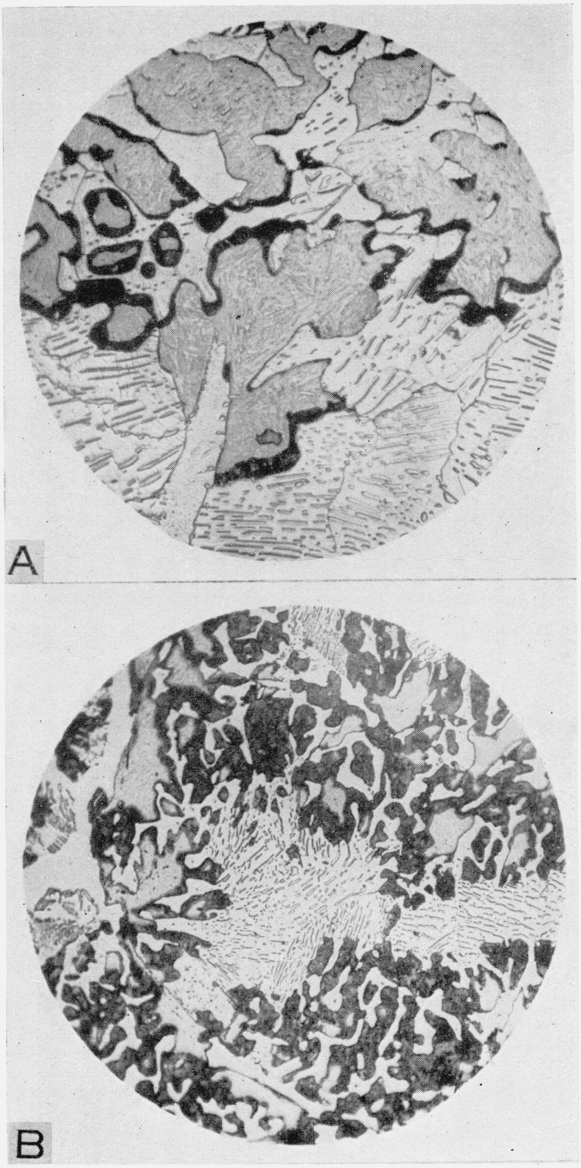

FIGURE 2.—*Nucleation and growth of austenite from fine pearlite at the* Ac_1 *temperature.*

A, A more advanced stage in the formation of austenite than that shown in figure 1. Note depletion of cementite lamellas near many of the original austenite areas (now martensite and troostite). ×1000.

B, A further stage in the formation and growth of austenite. Note finger-like growth of austenite areas (now martensite and troostite) and envelopment of small areas of ferrite. ×500.

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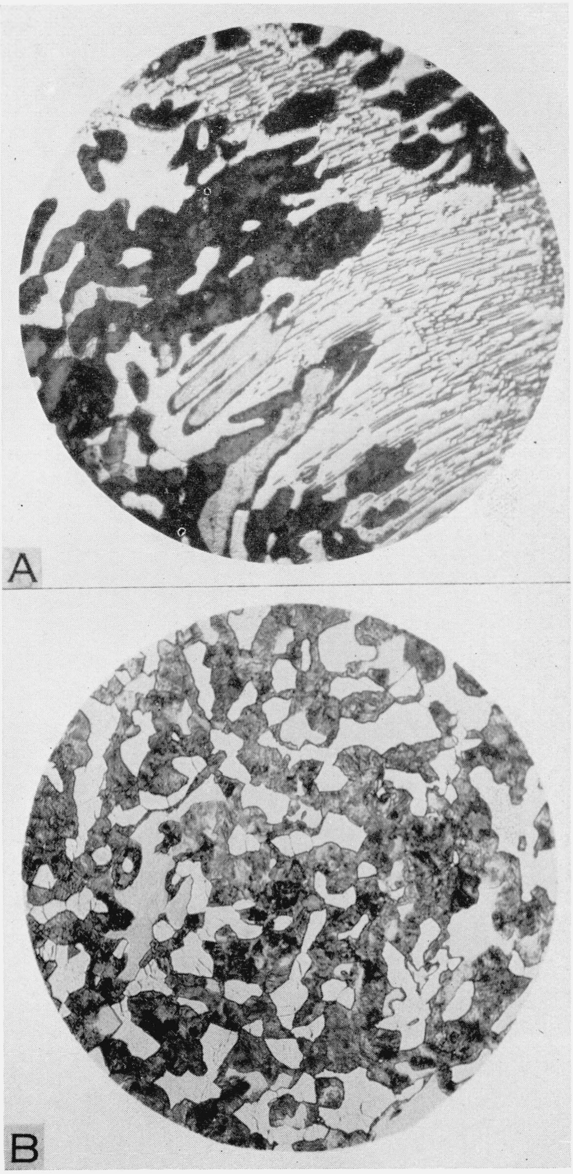

FIGURE 3.—*Nucleation and growth of austenite from fine pearlite at the Ac_1 temperature.*

A, The austenite, now martensite (light gray) and troostite (dark), has grown in a finger-like fashion in the direction of the lamellas. Note disappearance of cementite near many of the prior austenite areas, leaving ferrite (white). ×1000.

B, Structure after all the pearlite has transformed to austenite. Areas which were austenite at the time of quenching are now martensite and troostite. White areas are ferrite. ×500.

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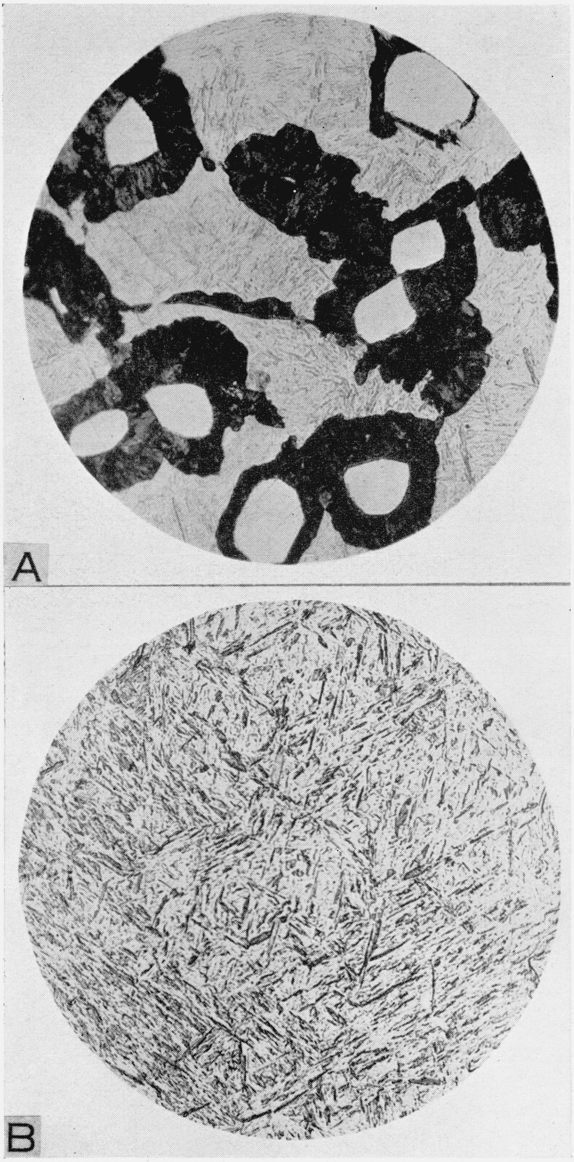

FIGURE 4.—*Absorption of ferrite by austenite formed from fine pearlite.*

A, Structure somewhat below Ac_3. Some of the ferrite (white) has not yet been absorbed by the austenite. On quenching, the austenite was transformed into martensite (light gray) and troostite (dark).

B, Structure just above Ac_3. All of the ferrite has been absorbed by the austenite (transformed to martensite on quenching).

Etched with 1 percent nital. ×500.

Figure 5, *B*, illustrates the formation of a minute area of austenite at the interface of a cementite and a ferrite lamella. It is postulated that cementite reacts with sufficient ferrite to form austenite of approximately eutectoid composition, which then grows (fig. 5, *C*) by absorbing cementite and part of the surrounding ferrite, thus leaving some excess ferrite. As this area of austenite spreads, a ferrite lamella is bridged (fig. 5, *D*), the cementite plate is completely absorbed, some of the carbon diffuses from an adjacent cementite plate into the austenite, and some of the ferrite is absorbed, leaving the remainder as free ferrite. Simultaneously, another grain of austenite begins at some other ferrite-carbide interface, and this grain grows in the same manner as the first grain. The austenite thus formed is of eutectoid carbon, although a carbon concentration gradient of submicroscopic dimensions must surely exist, since the austenite in contact with the cementite must be relatively high in carbon, whereas the austenite in contact with the ferrite must be relatively low in carbon. At a more advanced stage all of the cementite is consumed by the austenite, around which may be found more or less irregular areas of free ferrite (fig. 5, *E*). This growth occurs both in the direction of and across the lamellas. However, because the pearlite is carbon-poor, the austenite tends to grow in a fingerlike fashion along the cementite lamellas, which are carbon-rich, thus leaving free ferrite between. As the formation of austenite proceeds, some of these areas of ferrite are enclosed by the advancing austenite. At this stage the grains are invariably quite small. As growth continues, two or more grains will meet; whether they will merge depends upon such factors as time, temperature, relative size, orientation, etc. With sufficient time at this temperature (the Ac_1), all of the pearlite will transform to austenite (of eutectoid carbon content) thus leaving some free

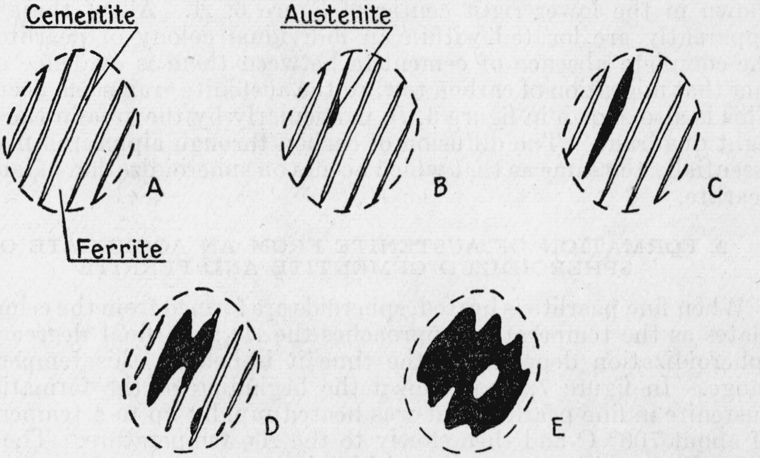

FIGURE 5.—*Sketch to illustrate nucleation and growth of austenite within a carbon-poor pearlite colony.*

Pearlite of eutectoid carbon (0.83% C) contains approximately 87.5 percent of ferrite and 12.5 per cent of cementite, or about 7 parts of ferrite for each part of cementite by weight. Pearlite of 0.50 percent C, therefore, contains about 11.6 parts of ferrite for each part of cementite.

ferrite. As the temperature is raised these ferrite areas, as well as the areas of proeutectoid ferrite, are gradually absorbed by the austenite until, at the Ac_3 temperature, all of the ferrite has been absorbed by the austenite, the carbon content of which is now 0.50 percent.

Comment has already been made on the fact that, since this pearlite is carbon-poor, if the austenite originally formed is of eutectoid composition, free ferrite must exist in conjunction with the austenite. Many of the structures examined suggested the possibility that, at the Ac_1, carbon diffused from the cementite of untransformed areas of pearlite to the adjoining austenite grains. This phenomenon was particularly evident in specimens which had been heated slowly and held for only 5 minutes in the vicinity of the Ac_1. Attention is directed to the several areas of martensite and troostite (originally austenite) shown in the lower right center of figure 6, *A*. All of these areas apparently are located within an individual colony of pearlite, yet the complete absence of cementite between them is evidence of the fact that migration of carbon toward the austenite grains has occurred. This is also shown in figure 6, *B*, particularly by the area in the lower right quadrant. The diffusion of carbon through alpha iron must be essentially the same as that which occurs on spheroidization of lamellar pearlite.

2. FORMATION OF AUSTENITE FROM AN AGGREGATE OF SPHEROIDIZED CEMENTITE AND FERRITE

When fine pearlite is heated, spheroids are formed from the cementite plates as the temperature approaches the Ac_1; the final degree of its spheroidization depends on the time it is held in this temperature range. In figure 7, *A* is shown the beginning of the formation of austenite in fine pearlite that was heated rapidly up to a temperature of about 700° C and then slowly to the Ac_1 temperature. The total time this specimen was held within the temperature range of about 700° C to the Ac_1 was about 22 minutes. Partial spheroidization occurred and the active nuclei for austenite formation were usually located in the vicinity of the ferrite boundaries.

Nucleation of austenite in an alloy with a structure containing cementite both as lamellas and as spheroids may occur at any cementite-ferrite interface. The formation of austenite from lamellar pearlite has already been described; its formation from an aggregate of spheroidized cementite and ferrite can best be studied by using specimens that have been intentionally spheroidized.

Specimens of the iron-carbon alloy with a structure of fine pearlite, therefore, were heated in vacuum in the temperature range of 680° to 720° C (below Ac_1) for about 9 hours. Although this treatment produced nearly complete spheroidization, the carbides tended to collect in the form of a network (fig. 7, *B*). Apparently this network bears no definite relation to the preexisting austenite grains from which the fine pearlite had been formed or to the colonies of pearlite in the initial structure. Had the period of the spheroidizing treatment been prolonged sufficiently, it seems possible that nearly all the carbides would have collected in the network. This is evidenced by the results of a microscopic examination, which showed either no indication of carbides or only small and finely divided particles in a few of the areas enclosed by the network.

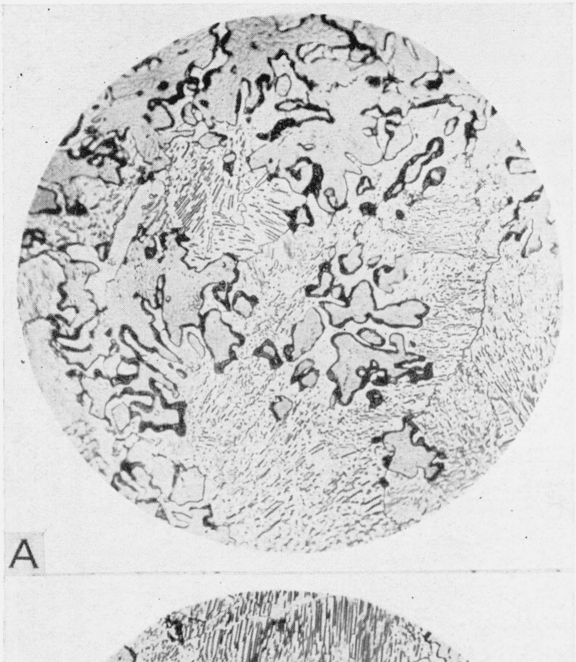

FIGURE 6.—*Formation of austenite from fine pearlite at the Ac_1 temperature.*

A, Note depletion of cementite between austenite grains (now martensite and troostite) in colony of pearlite shown in lower right center of photomicrograph.

B, Note depletion of cementite in areas adjacent to austenite (now martensite and troostite), particularly in lower right quadrant of photomicrograph.

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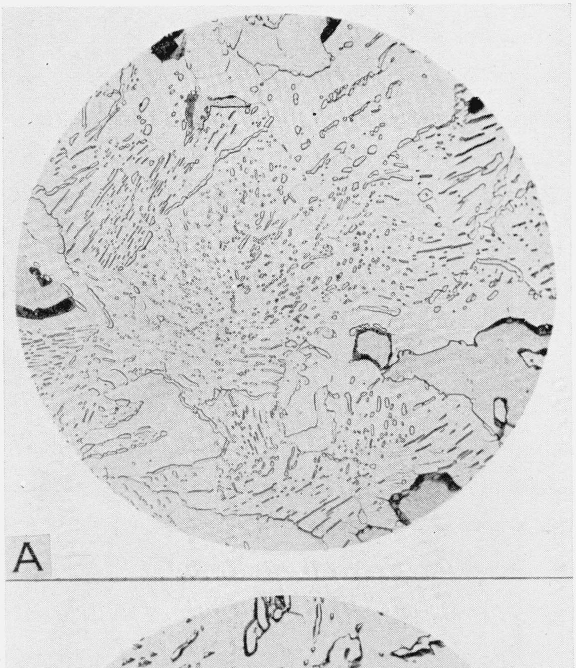

FIGURE 7.

A, Nucleation of austenite from fine pearlite at the Ac_1 temperature. Specimen was heated slowly. Note partial spheroidization. Etched with 1 percent nital. ×500.

B, Structure of iron-carbon alloy after spheroidization. Note tendency of carbides to collect in the form of a network. Etched with 1 percent nital. ×500.

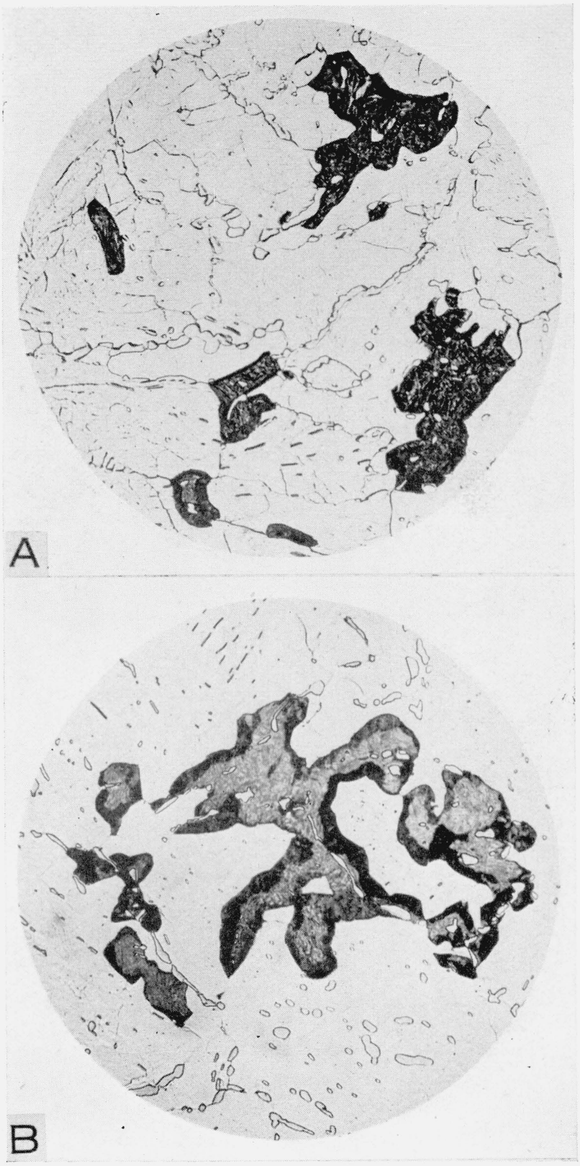

Figure 8.—*Nucleation and growth of austenite from aggregates of spheroidized cementite and ferrite at the Ac_1 temperature.*

A, The austenite grains (now martensite and troostite) were nucleated at the interfaces of ferrite and the carbide network and, in some cases, at interfaces within the interior of the network.

B, The austenite grains (now martensite and troostite) have grown preferentially along the cementite network. Note almost complete disappearance of carbides from the ferrite enclosed by the originally austenite grains.

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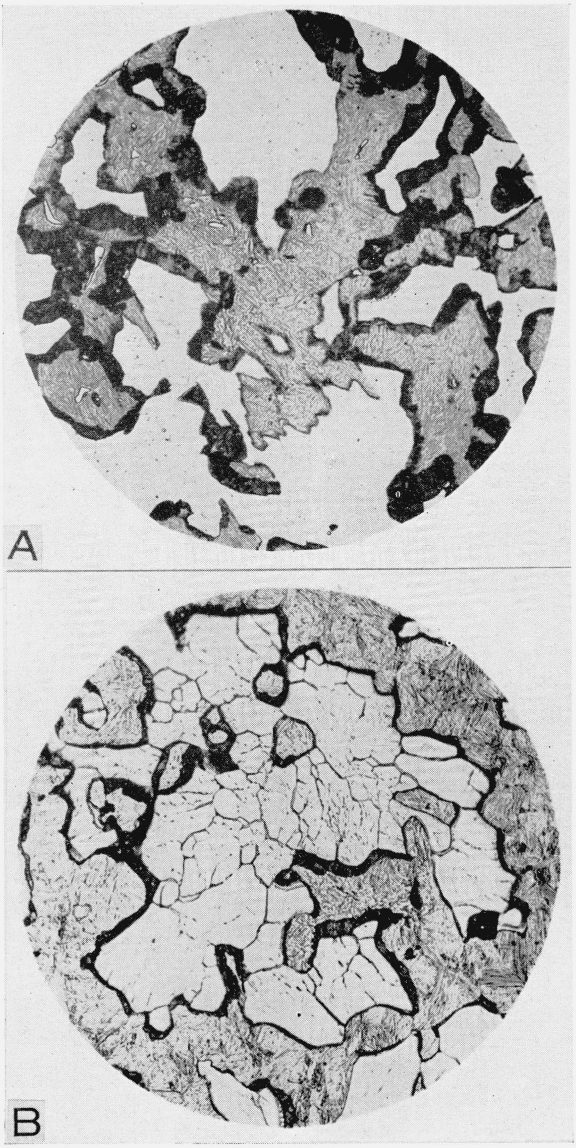

FIGURE 9.—*Nucleation and growth of austenite from an aggregate of spheroidized cementite and ferrite at the Ac_1 temperature.*

A, The formation of austenite (now martensite and troostite) of eutectoid carbon is nearly complete. Note almost complete absence of carbides in the ferrite. Austenite still contained occasional undissolved carbides at the time of quenching.

B, The formation of austenite of eutectoid carbon is complete. Only two phases exist—ferrite (white) and austenite (transformed into martensite and troostite).

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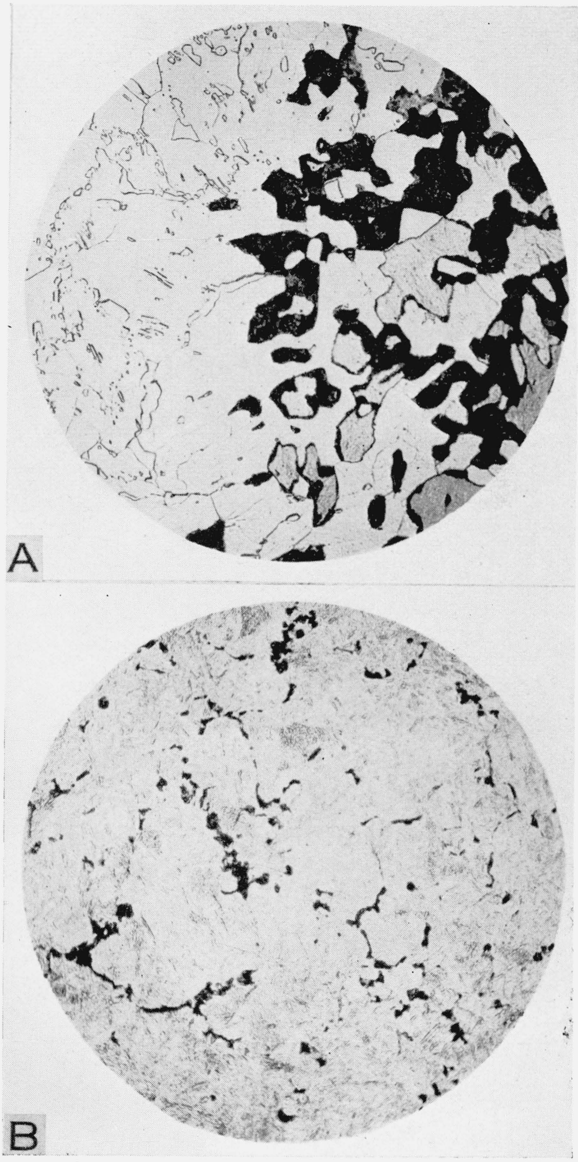

FIGURE 10.—*Effect of time and temperature on the size of austenite grains.*

A, The grains of austenite (now martensite and troostite) formed at the Ac_1 temperature are quite small. The structure was originally fine pearlite, which spheroidized during the slow heating. ×500.

B, Same specimen as *A*. The grains of austenite, transformed into martensite with troostite at the boundaries, are quite large at the Ac_3 temperature. ×100.

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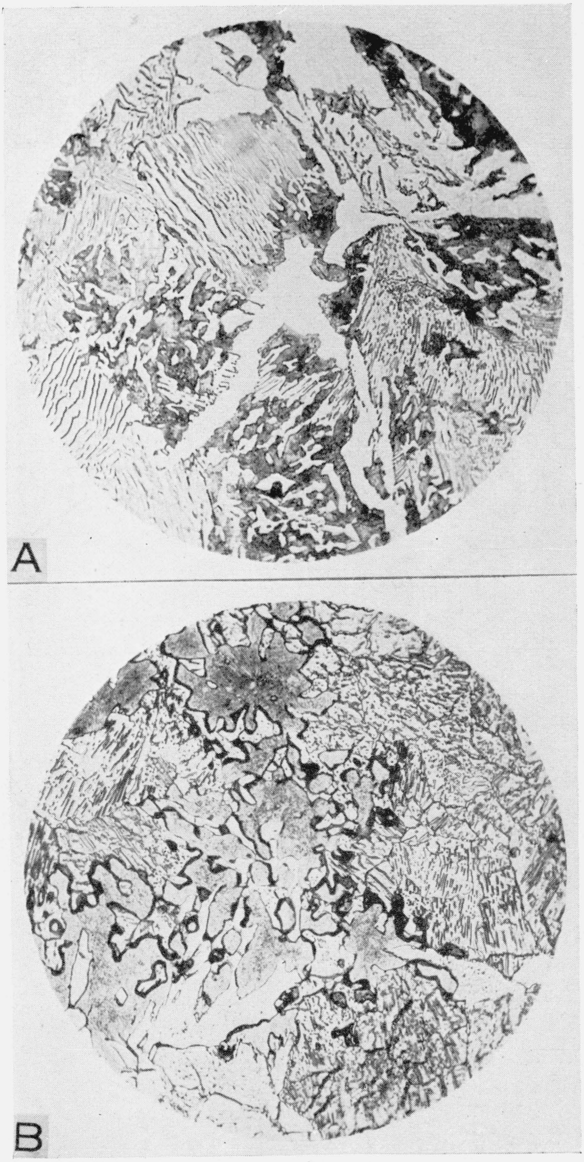

FIGURE 11.—*Effect of rate of heating on nucleation of austenite from fine pearlite at the Ac_1 temperature.*

A, Heated very rapidly. Note considerable number of active nuclei as evidenced by the numerous small areas of troostite.

B, Heated rather slowly. Note smaller number of active nuclei, as evidenced by the fewer and larger areas of martensite and troostite.

Etched with 1 percent nital. ×500.

When a specimen with such a spheroidized structure was heated to the Ac_1 temperature, austenite grains were nucleated at the interface of ferrite and the carbide network, and, in some cases, at the interface of ferrite and carbide within the network, as shown by the decomposition products of austenite in figure 8, *A*. With increase in either time or temperature, the newly formed austenite grains grew and new grains were formed, usually along the network, as illustrated in figure 8, *B*. Simultaneously with this initial formation of austenite, the carbides located within the network, which were not active as centers for nucleation, decreased in number and size by the diffusion of carbon to the network or to the existing grains of austenite (fig. 8, *B*). This phenomenon might be viewed simply as a further step in the spheroidization of the cementite.

Nucleation, growth, and diffusion continued, and a stage was reached where the austenite grains merged in the neighborhood of the original cementite network, thus leaving only a few finely divided carbides embedded in the ferrite, as illustrated in figure 9, *A*. It is noteworthy that at this stage of the transformation the austenite contained some undissolved carbide particles that were considerably larger than the remaining carbides embedded in the ferrite or untransformed portion of the specimen. Since this transformation had been occurring at the Ac_1 temperature, it is apparent that the austenite was of approximately eutectoid composition. However, carbon gradients must have existed in the austenite which was in contact with cementite in the interior of the grains and with ferrite at the grain boundaries. With increase either in time at this temperature or in temperature, the carbon from the cementite continued to diffuse through the austenite to the austenite-ferrite boundary, where additional austenite was formed. Simultaneously, the carbides located in the ferrite continued to be absorbed until the alloy reached equilibrium, and consisted of two phases, austenite (transformed to martensite and troostite) and ferrite, as is shown in figure 9, *B*. Upon heating to the Ac_3 temperature or above, the absorption of ferrite was completed and the austenite attained a uniform composition (0.50 percent of carbon).

3. EFFECT OF RATE OF HEATING ON NUCLEATION OF AUSTENITE

Variation in the rate of heating through the Ac_1-Ac_3 transformation range is known to have a marked influence on the austenite grain size of this alloy at temperatures either just above or considerably higher than the Ac_3 [1, 3]. Relatively fine grains are produced by rapid heating and coarse grains by slow heating. However, even on slow heating through the Ac_1 transformation, sufficient nuclei become active to render the austenite fine-grained in the initial stage of its formation. This is shown by the microstructure in the zone of transformation (fig. 10, *A*) of a specimen that was differentially heated, so that a portion was heated slowly through the Ac_1 and held for 15 minutes before quenching. The austenite was fine-grained when first formed, but it was coarse-grained, figure 10, *B* (estimated ASTM grain No. 2 to No. 4), at the Ac_3 temperature.

Although with relatively slow rates of heating sufficient nuclei act to produce fine-grained austenite, this condition does not necessarily imply that the rate of heating does not influence the rate of nucleation of this alloy. It is believed that the rate of heating does affect the rate of nucleation. With this high-purity alloy, which is relatively free from grain-growth inhibitors, more nuclei are effective in the formation of austenite from fine pearlite when heating is relatively rapid than when heating is slow.

The more rapidly fine pearlite is heated through the Ac_1 temperature, the more numerous are the active nuclei. The initial formation of austenite in the low-carbon pearlite of a specimen which was heated very rapidly to the Ac_1 (50 seconds from room temperature to the Ac_1) and then immediately quenched is shown by its decomposition products in figure 11, *A*, and the initial transformation in another specimen of the same material when heated rather slowly to the Ac_1, held for 5 minutes and then quenched, is shown in figure 11, *B*. The austenite grains initially formed in each specimen were very small indeed, but it is apparent that more nuclei were active in forming austenite in the rapidly heated specimen (fig. 11, *A*) than in the one heated rather slowly (fig. 11, *B*) or in the one heated very slowly (fig. 10, *A*). It is further apparent that the austenite grains were larger and less numerous in the slowly heated specimens than in the rapidly heated specimen.

It is evident that when such an alloy is heated to the Ac_1 temperature certain nuclei become active in formation of grains of austenite. If the rate of heating is slow, relatively few nuclei are effective and ample time exists for growth of these grains. If the rate of heating is very rapid the alloy is, in effect, superheated; a considerable number of nuclei then become active because of the higher temperature at which the Ac_1 transformation occurs. Determinations of the Ac_1 showed that, when the alloy was heated slowly, this transformation began at about 725° C, whereas, with very rapid heating, it occurred at about 740° C. Had the rapidly heated specimen been held just above the Ac_1 temperature, it is believed that considerable growth would have taken place in the austenite grains.

Since the final austenite grain size depends upon the rate of nucleation and rate of growth, it is evident that, for this alloy, the latter is the dominant factor in establishing this grain size. With this high-purity alloy, and with other alloys of similar purity but having higher percentages of carbon, rapid growth occurred within the transformation temperature range when heating was slow. That is, these alloys are very susceptible to coarsening within the temperature range of the Ac_1-Ac_3 transformation. Whether coarsening occurred within this range depended upon the rate of heating (time within this temperature range). At temperatures as high as 980 ° C, however, these alloys were coarse-grained, regardless of the rate of heating.

V. SUMMARY

1. A study was made of the nucleation and growth of austenite on heating a high-purity alloy of iron and carbon containing 0.50 percent of carbon. The changes that occurred in both fine pearlite and an aggregate of spheroidized cementite and ferrite were followed by differentially heating small specimens in vacuum at various rates to temperatures within and slightly above the Ac_1-Ac_3 transformation range and quenching directly in helium. The different stages in the formation of austenite from the aggregates of ferrite and carbide are shown in photomicrographs and illustrated schematically.

2. On heating fine pearlite (plus ferrite), austenite was nucleated at the interfaces of ferrite and carbide, preferentially at the boundaries of pearlite and proeutectoid ferrite and at the boundaries of the pearlite colonies. It was also nucleated occasionally within the pearlite colonies. Fingerlike growths (irregular shapes) occurred, usually in the directions of the lamellas, but growth also extended across the lamellas.

3. During spheroidization of this alloy the carbides tended to collect in the form of a network. On heating a specimen with such a structure, austenite started to form at ferrite-carbide interfaces, usually at the cementite network and to some extent within the network. In the initial stages of transformation these grains grew preferentially along the cementite network.

4. During the formation of austenite from fine, carbon-poor pearlite or an aggregate of spheroidized cementite and ferrite, the carbon diffused through ferrite to the austenite grains and also through the austenite during the absorption of the ferrite.

5. Regardless of the rate at which this alloy was heated through the Ac_1 transformation, austenite was nucleated at numerous interfaces of ferrite and carbide, so that in the initial stage of its formation the austenite was *always* fine-grained. However, rapid grain growth may occur in the Ac_1-Ac_3 transformation range by the absorption or coalescence of the grains initially formed. If the rate of heating through the Ac_1-Ac_3 transformation range was extremely rapid, this grain growth was largely inhibited, and the resulting austenite was relatively fine-grained at temperatures considerably above the Ac_3. If heating was less rapid, grain growth was not inhibited, and the resulting austenite was very coarse-grained. The predominant factor in establishing the final austenite grain size of this alloy, therefore, was the rate of growth and not the rate of nucleation.

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