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Seventh Quarterly Progress Report

on

THE TRANSFORMATION OF AUSTENITE UNDER EXTERNALLY APPLIED TENSILE STRESS

For the Period September 1, 1953 to November 30, 1953

by

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SEVENTH QUARTERLY PROGRESS REPORT

on

THE TRANSFORMATION OF AUSTENITE UNDER EXTERNALLY APPLIED TENSILE STRESS

This report constitutes a summary of work done with respect to an electron microscopic study of the bainites of AISI 1085, 4340, and 1045 steels, isothermally transformed both under no stress and an applied stress of 60,000 psi.

The temperature levels investigated were 450°, 535°, and 700°F for AISI 1085 steel, 650° and 845°F for AISI 4340 steel, and 700°F for AISI 1045 steel.

Experimental Procedure:

a. The Preparation of Replica:

The specimens were polished by conventional techniques and etched lightly in saturated picral. A one-step replica technique was used. The replica solution consisted of one part of collodion and three parts of amyl acetate. The replica was subsequently shadowcast with palladium at about a 30° angle. This was the final stage in the preparation of the replica and after shadowing, the replica was placed within the electron microscope.

b. Examination of the Replica Under Electron Microscope and the Taking of the Pictures:

Ten pictures of each sample were taken. The initial magnification used in taking these pictures varied between 6,000 to 10,000 diameters, although in some cases pictures at magnifications as low as 3,000 diameters and as high as 22,000 diameters were taken.

The picture negatives were reverse printed. In making the positive prints, the intermediate negatives were generally enlarged twice in diameter using projection printing technique.

c. Interpretation of the Black and Varying Shades of Grey Areas in the Prints:

To aid in the interpretation of the black and varying shades of grey areas in the prints, a random print has been chosen and is shown in Fig. 1.

The picture consists of a distribution of dark grey or black areas in a lighter grey matrix. Surrounding every black area on one side is an area of greyish-white color which is lighter than the general light grey background. These different areas of black, grey and light grey in the picture can be better understood with the help of sketches shown in Figs. 2 (a) and 2 (b).

Fig. 2 (a) illustrates the appearance of a specimen after a layer of plastic has been poured on the etched surface. The etchant has attacked and dissolved the ferrite matrix to a greater degree than it has attacked either the cementite particles or the inclusions. Thus the cementite particles and the inclusions appear to be raised on the surface.

Fig. 2 (b) shows the plastic replica after it has been stripped off the specimen surface and shadowed.

The projecting cementite particles and inclusions result in depressions of varying depth and width in the plastic replica after it has been stripped off the surface. The specimen surface has been shadowcast with palladium at an angle of about 30°.

When the palladium metal evaporates, it deposits on the surface of the replica and on some parts of the depressions in the surface, depending on the angle of shadowing. Wherever the angle of shadowing increases above 30° due to the geometry of the surface, the amount of metal deposited

becomes larger than the amount deposited uniformly on the surface which is at 30°. This is schematically shown in Fig. 2 (b).

When an electron beam is allowed to pass through a shadowed replica like the one shown in Fig. 2 (b) and made to react with a photographic emulsion, black and shades of grey areas result in the negative. This is shown in Fig. 1.

The electrons passing through the uniformly distributed layer of palladium on the flat surface of the replica (which corresponds to the ferrite matrix in the structure) produce a uniform grey background in the negative. The depressions in which palladium could not deposit, allow the electrons to pass through unobstructed, producing the black areas in the negatives. Portions of the surface, especially sides of the depressions in the replica, receive a much heavier coating of palladium than the average and these portions of the replica allow fewer electrons to pass through, resulting in lighter grey areas in the negative. As mentioned above, an intermediate negative is made of each original negative and prints are then made from this intermediate negative. Thus, in the prints, an exact sequence of black and shades of grey areas is obtained, as observed in the original negative.

d. Study of the Electron-Photomicrographs:

1. 1085 Steel Isothermally Transformed at 700°F.

A series of electron-photomicrographs for 1085 steel at the upper bainite transformation temperature of 700°F under no stress and a stress of 60,000 psi is shown in Figs. 3 and 4, respectively.

It can be observed from these pictures that the structure of bainites formed under no stress and an applied stress are very similar. The size and distribution of cementite particles in the ferrite matrix are not noticeably affected by the applied stress. Most of the apparent difference

in size of the cementite particles is a result of the differences in orientation of the cementite particles with respect to the plane of polish. Figs. 3 (d) and 4 (d) illustrate the arrangement of the cementite particles inside colonies in grains. There is little evidence of any distorted or unorganized structure in the colony boundaries. In both Figs. 3 (d) and 4 (d), the cementite platelets inside the colonies have pronounced directional orientation, indicating that this directional effect is not caused by the applied stress.

2. 1085 Steel Isothermally Transformed at 535°F.

A series of electron-photomicrographs for 1085 steel at the lower bainite transformation temperature of 535°F is shown in Figs. 5, 6, and 7. Fig. 5 illustrates a bainitic structure formed under no stress. Figs. 6 and 7 illustrate bainitic structures formed under a stress of 60,000 psi, but for transformation times of 750 sec. and 1800 sec., respectively. In 750 sec., at a stress of 60,000 psi, about 99% bainite is obtained; in 1800 sec., under the same amount of stress, the transformation is complete. These observations were made in order to study the effect of a prolonged transformation time(much in excess of time required for a virtually complete transformation (99%)) on the microstructure of bainite, as revealed under electron-microscope.

As observed in the upper bainite structure, the size and distribution of the cementite particles are virtually unaffected by applied stress at the lower bainite transformations as shown in Figs. 5, 6, and 7. The striking appearance of several bainite needles in Fig. 5 (a) indicates that the structure is lower bainite, since in the upper bainite structure this pattern of arrangement of cementite particles is practically absent. In both the stressed structures shown in Figs. 6 and 7, no such distinct appearance of bainite needles is evidenced, although in Fig. 6 (a), 7 (a), and 7 (c)

the needles are visible. The appearance of a needle-like arrangement of cementite particles on the specimen surface is purely a matter of chance, for to produce a needle-like appearance, the plane of polish must intersect a particular needle in a special way. This rarely occurs because of the needles' random orientation. The orientation of the cementite particles inside a needle is observed to be about 55° to the needle-axis, the same being observed by other workers. (1)

3. 1085 Steel Isothermally Transformed at 450°F.

A series of electron-photomicrographs of bainite transformed at the temperature of 450°F, both under no stress and an applied stress of 60,000 psi is shown in Figs. 8 and 9.

In this lower bainite structure a large number of needles is observed in both the unstressed and stress-transformed structures. The usual orientation of the carbide particles inside the needles, namely, the 55° orientation with the needle axis, is also evidenced here. The needles have sharply outlined tips and the carbide particles, still maintaining their characteristic orientation, gradually become smaller to accomodate themselves right up to the tip of the needle. This is clearly indicated in Fig. 8 (c).

In Figs. 8 and 9, small areas of martensite indicate the prior existance of austenite which was untransformed when the transformation reactions were stopped by quenching in an air blast. Martensitic areas, like carbide particles, being more resistant to the attack of the etchant than ferrite, appear in these pictures as raised (or depressed) areas from the general surface of the ferrite matrix. In such a martensite area in Fig. 8 (c), one observes a depression, which thus corresponds to a

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(1) Report of Committee E-4 on Metallography: Proc. Amer. Soc. Testing Materials, 50, 44 (1950)

small bainite area. In this bainite area, no detectable amount of carbide particles is present in the ferrite matrix. This is because in the limited area, the amount of carbide particles precipitated is very small, and their orientations are such that the plane of polish does not intersect any one of them. The size and distribution of the carbide particles seem to indicate that the carbide particles shown in Fig. 8 (c) are slightly larger than those shown in Fig. 9 (c).

4. 4340 Steel Isothermally Transformed at 845°F.

A series of electron-photomicrographs of bainites of 4340 steel formed under no stress and a stress of 60,000 psi is shown in Figs. 10 and 11, respectively.

In Fig. 10 martensite is present. This indicates that the time of isothermal transformation (indicated below the electron-photomicrographs in Fig. 10) was such that about 70-75% of austenite transformed to bainite at the temperature of transformation. On quenching, the remainder of the austenite transformed to martensite, as shown in Fig. 10.

In Fig. 11 one observes very small amounts of martensite. These bainitic structures were formed under stress and, for the isothermal transformation times indicated below the pictures, the transformation is virtually complete, i.e., about 95% for holding time of 10,000 sec. and about 99% for that of 100,000 sec. A comparison of the size of carbide particles indicates that in bainites formed under no stress and a stress of 60,000 psi held for 100,000 sec. carbide particles are probably somewhat larger than those in bainites transformed under the same conditions of stress but for a time of 10,000 sec. only.

Occasional distributional effects have been observed in carbide particle arrangements, both in the unstressed and stressed structures, an example of which is shown in Fig. 11 (a). In other respects the

electron-microstructures of bainites formed with and without applied stress are practically the same.

5. 4340 Steel Isothermally Transformed at 650°F.

A series of electron-photomicrographs for 4340 steel transformed at 650°F under no stress and a stress of 60,000 psi is shown in Figs. 12 and 13.

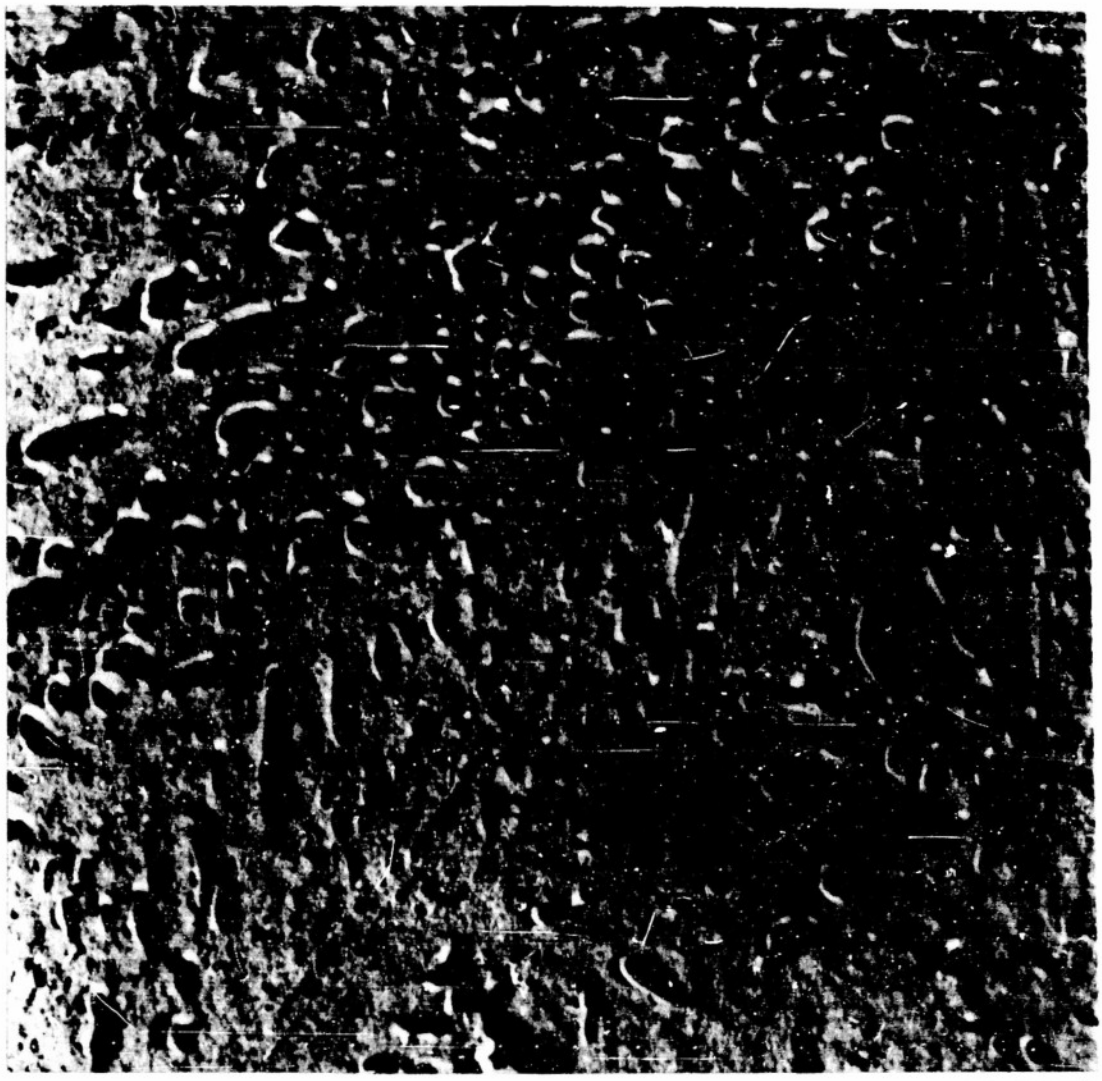
These pictures indicate that the structure of bainites formed with and without stress are very similar. The size and distribution of the carbide particles is caused by the random orientation of the needle and carbide particles with respect to the plane of polish. As in the case of 1085 steel, the carbide particles inside a needle are also oriented at approximately an angle of 55° to the needle axis.

6. 1045 Steel Isothermally Transformed at 700°F.

A series of electron-photomicrographs of bainites of 1045 steel formed under no stress and a stress of 60,000 psi is shown in Figs. 14 and 15, respectively. In 1045 steel, as observed in other steels, the shape, size, and distribution of the cementite particles in ferrite matrix in both the structures formed under no stress and an applied stress are largely identical. The absence of the characteristic arrangement of the carbide platelets indicates that very few needles are present, probably because of the relatively high temperature of transformation and low carbon content of the steel.

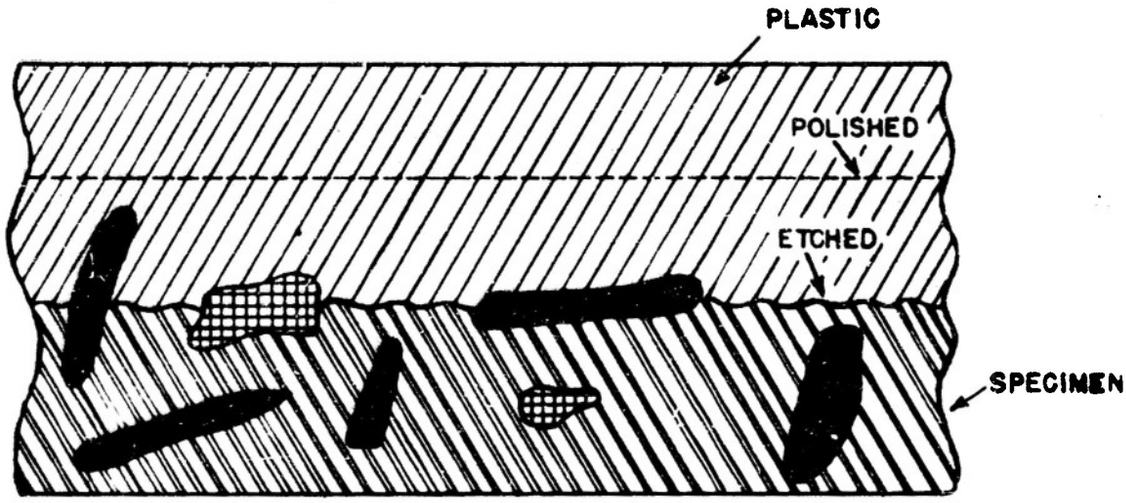
George L. Kehl

George L. Kehl
Project Director



46,000 X

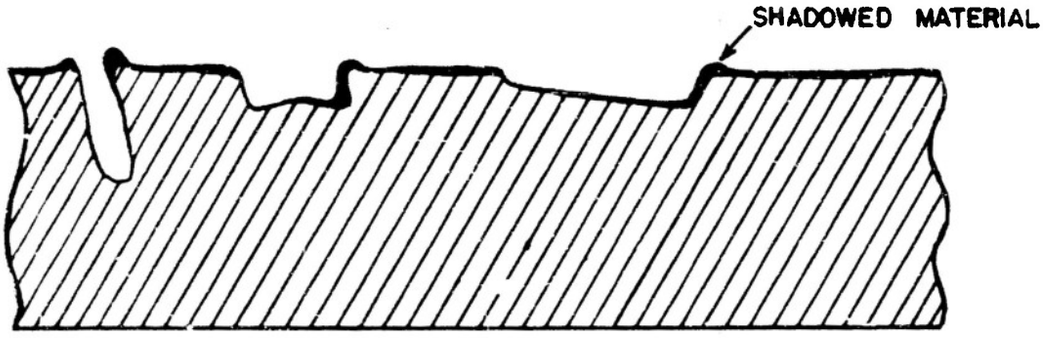
Fig. 1 Electron-photomicrograph of bainite showing black and varying shades of grey areas.



(a) ETCHED SPECIMEN SURFACE WITH REPLICA SOLUTION POURED ON IT

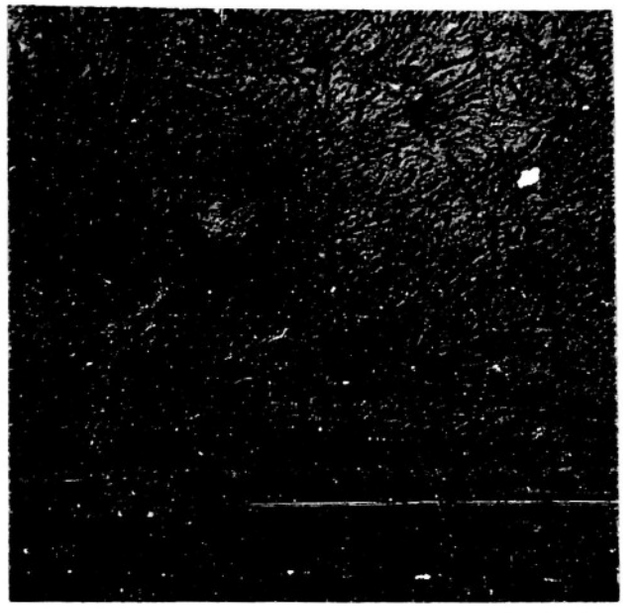
— CEMENTITE PARTICLE

— INCLUSION

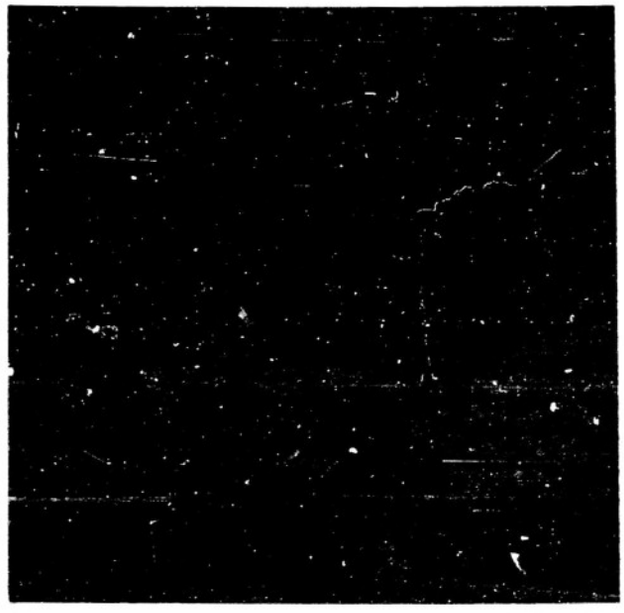


(b) REPLICA SURFACE AFTER BEING SHADOWCAST

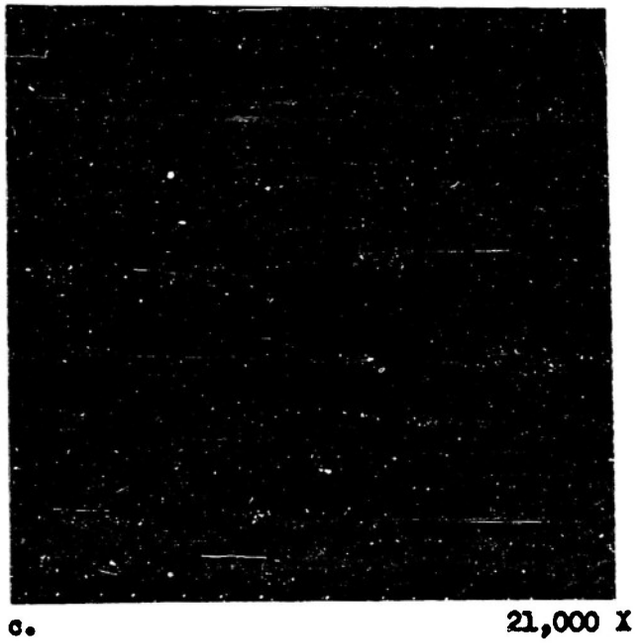
FIG. 2 ONE-STEP REPLICA TECHNIQUE SHOWN SCHEMATICALLY



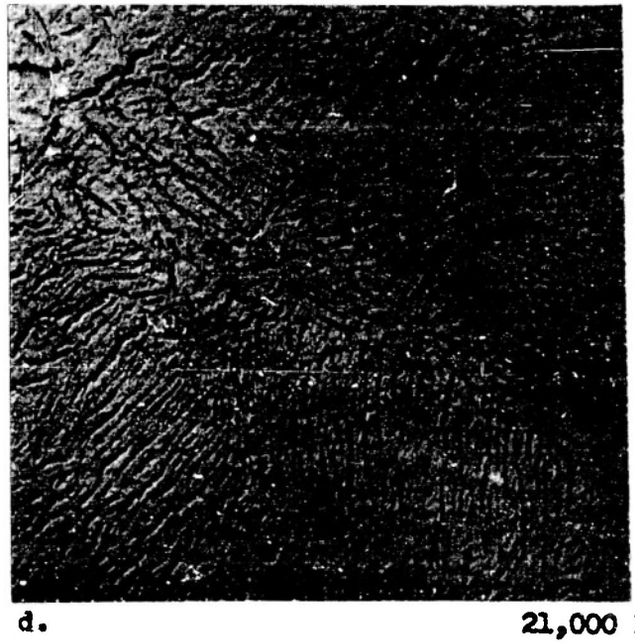
a. 12,000 X



b. 12,000 X

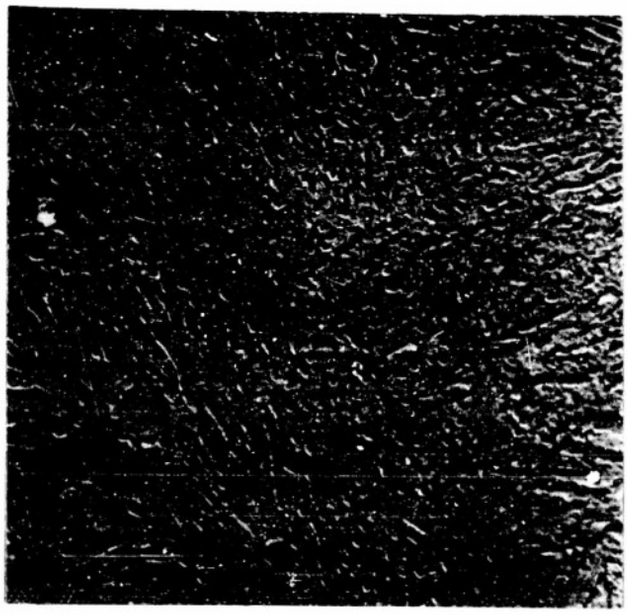


c. 21,000 X

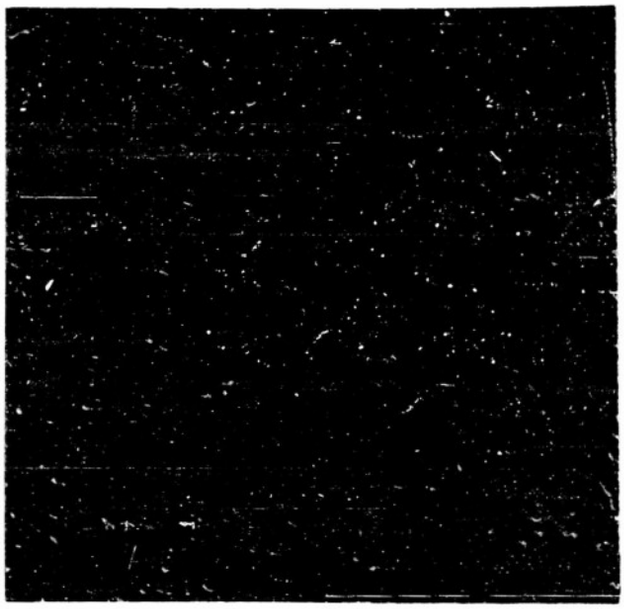


d. 21,000 X

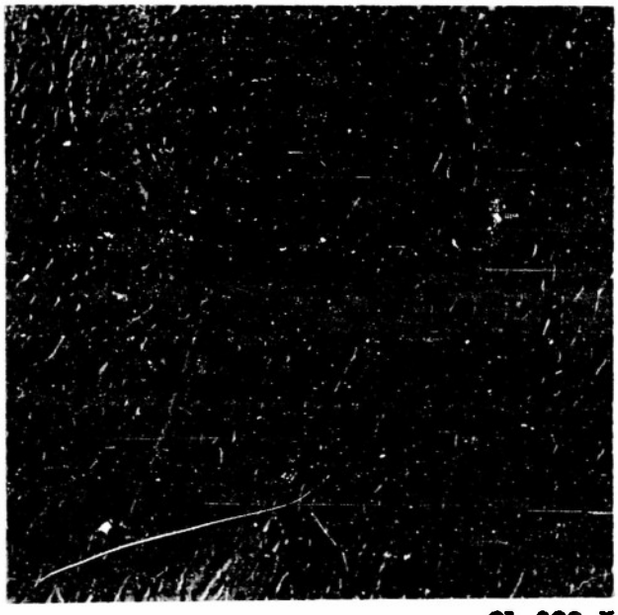
Fig. 3 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 700°F for 150 sec. under no applied stress



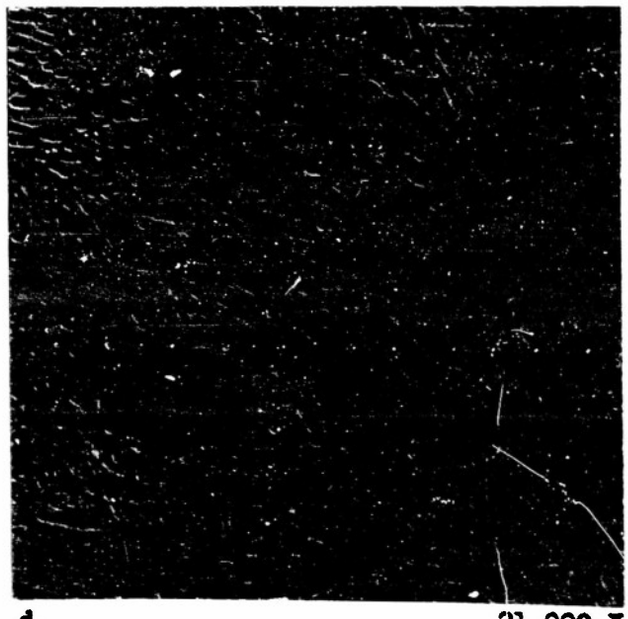
a. 21,000 X



b. 21,000 X

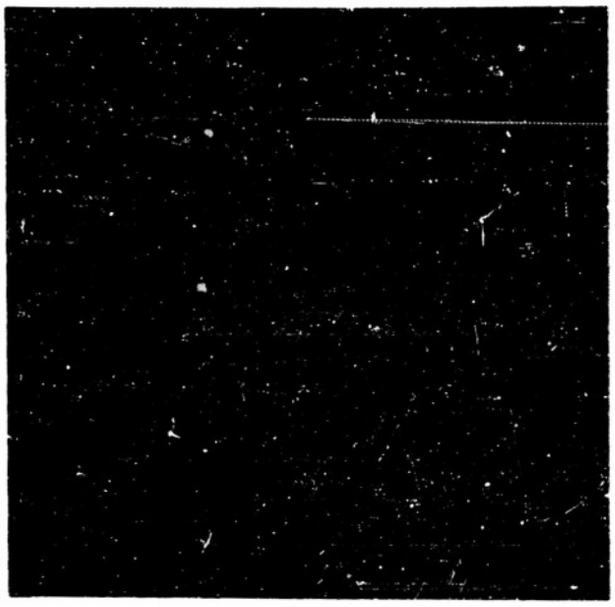


c. 21,000 X



d. 21,000 X

Fig. 4 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 700°F for 60 sec. under 60,000 psi stress

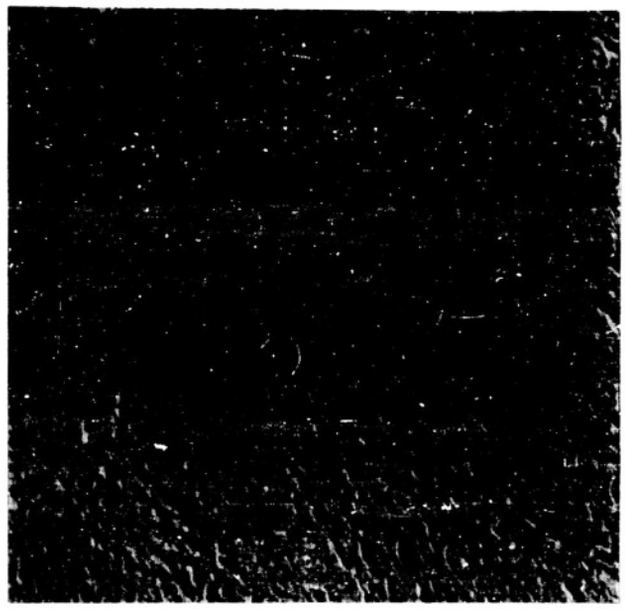


a. 8000 X

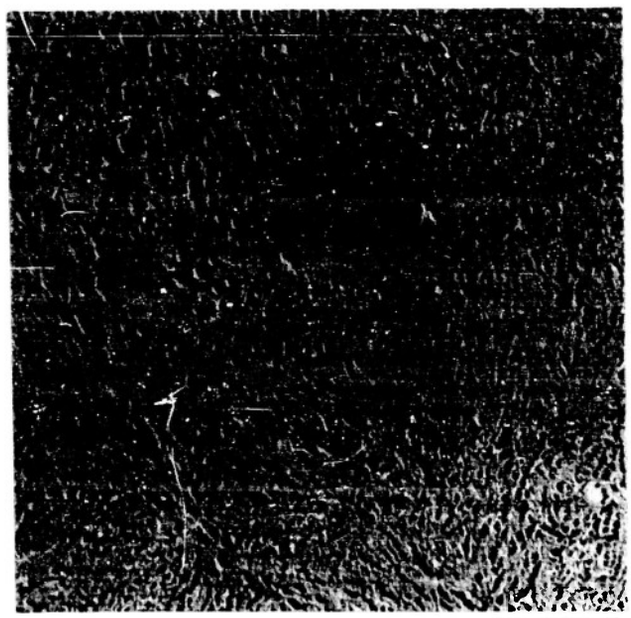
b. 12,000 X

c. 12,000 X

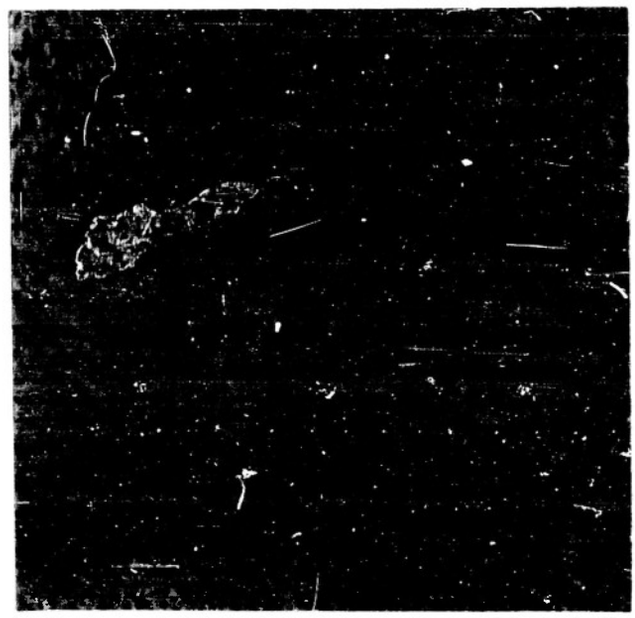
Fig. 5 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 535°F for 1500 sec. under no applied stress



a. 12,000 X

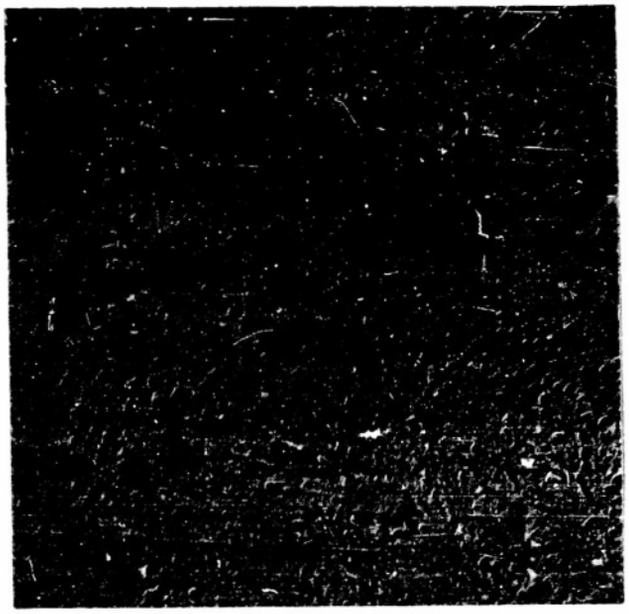


b. 12,000 X

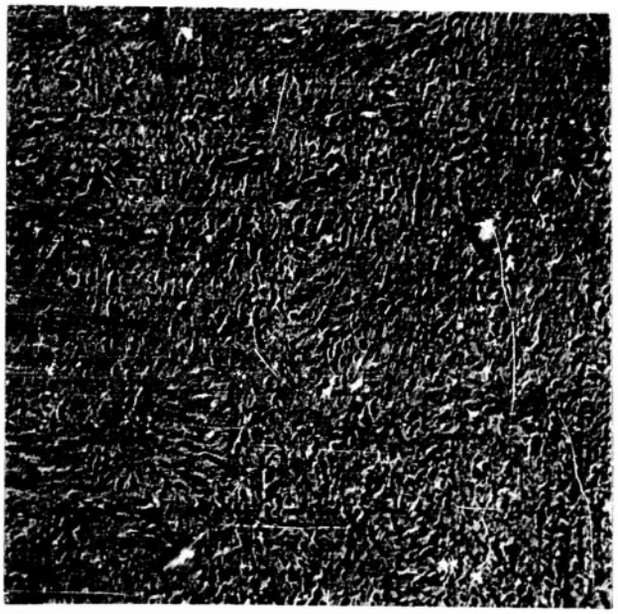


c. 21,000 X

Fig. 6 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 535°F for 750 sec. under 60,000 psi stress.



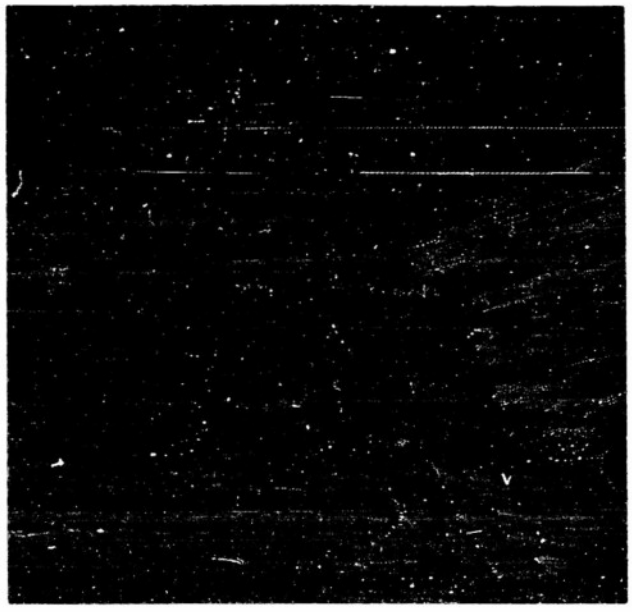
a. 12,000 X



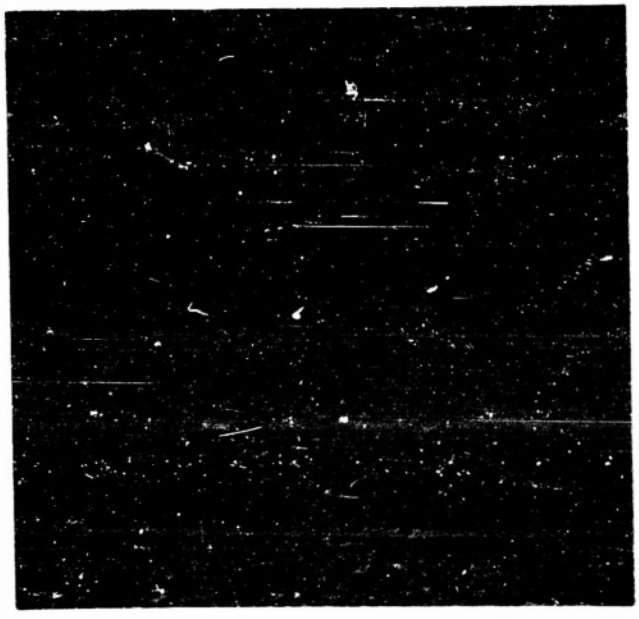
b. 12,000 X

c. 21,000 X

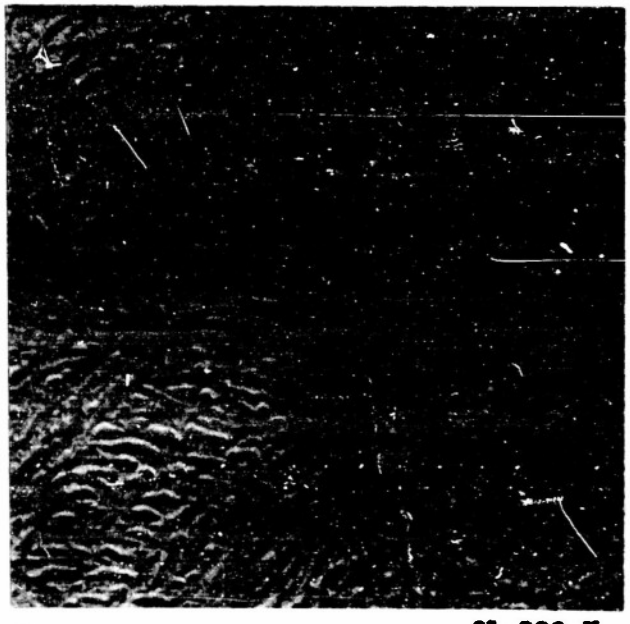
Fig. 7 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 535°F for 1800 sec. under 60,000 psi stress



a. 21,000 X

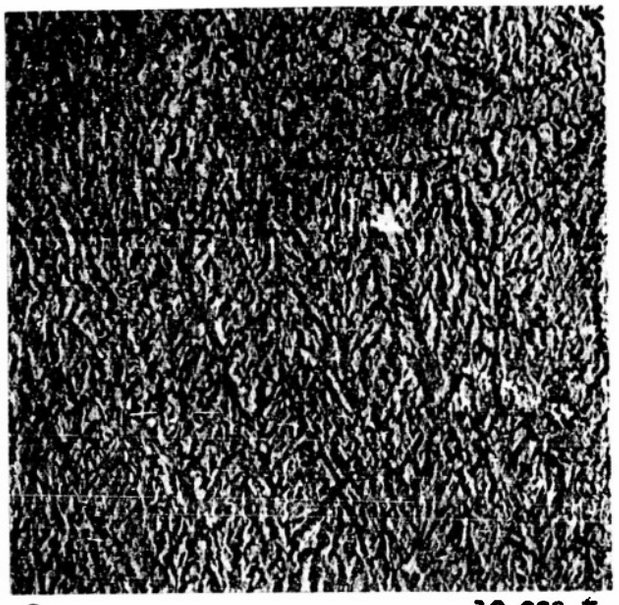


b. 21,000 X

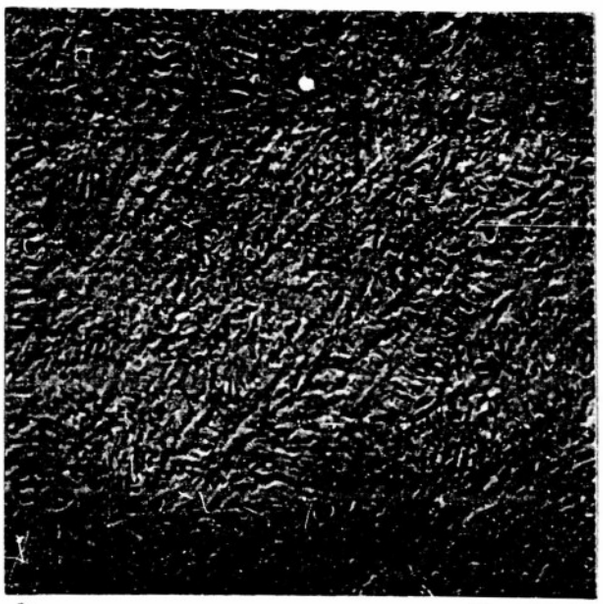


c. 31,000 X

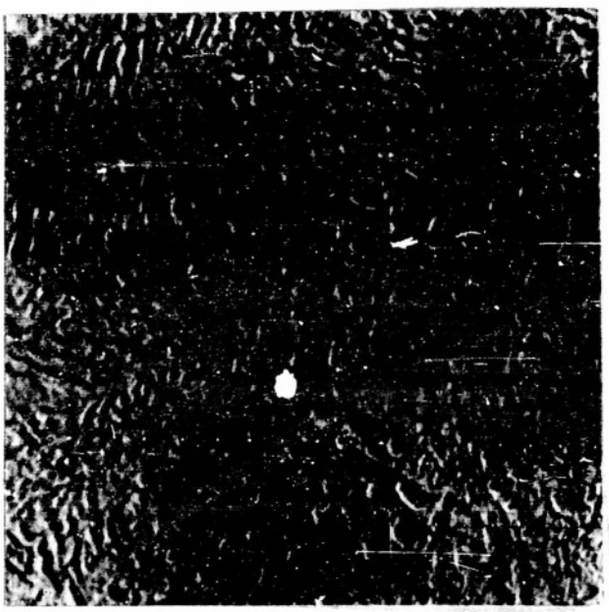
Fig. 8 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 450°F for 8000 sec. under no applied stress



a. 12,000 X

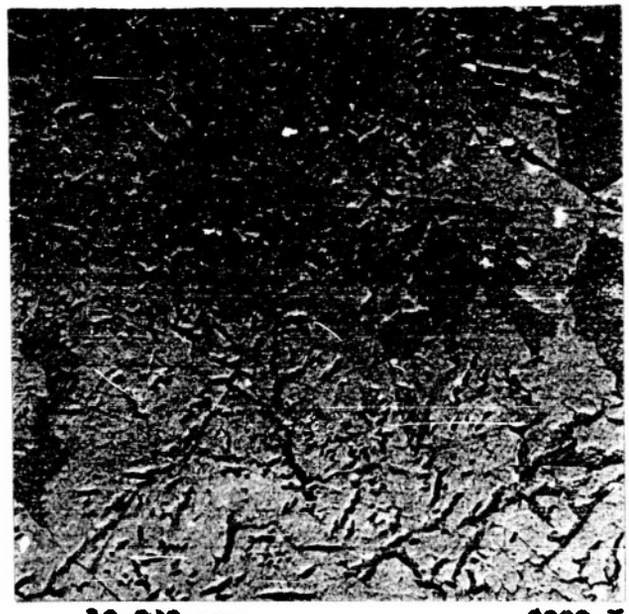


b. 21,000 X



c. 31,000 X

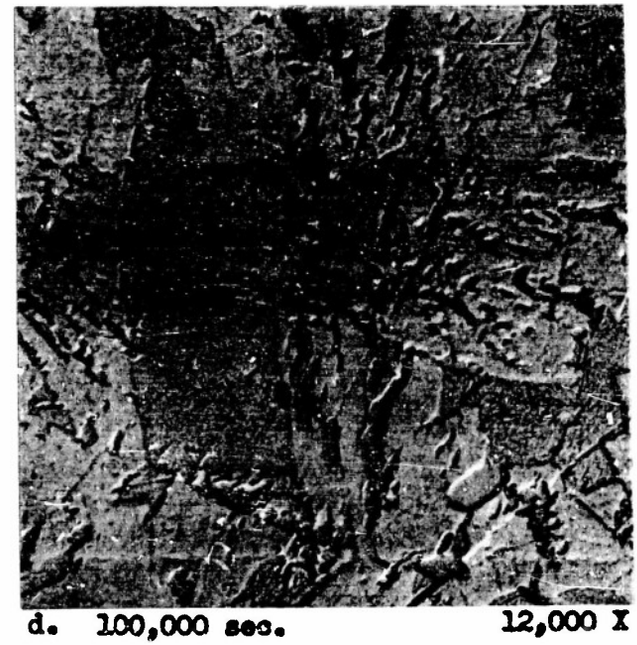
Fig. 9 Electron-photomicrographs of bainite; 1085 steel isothermally transformed at 450°F for 3000 sec. under 60,000 psi stress



a. 10,000 sec. 8000 X

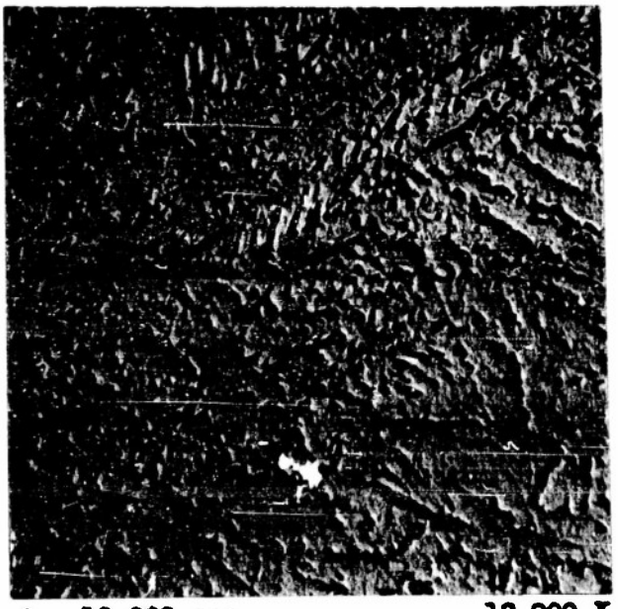
b. 10,000 sec. 12,000 X

c. 100,000 sec. 12,000 X

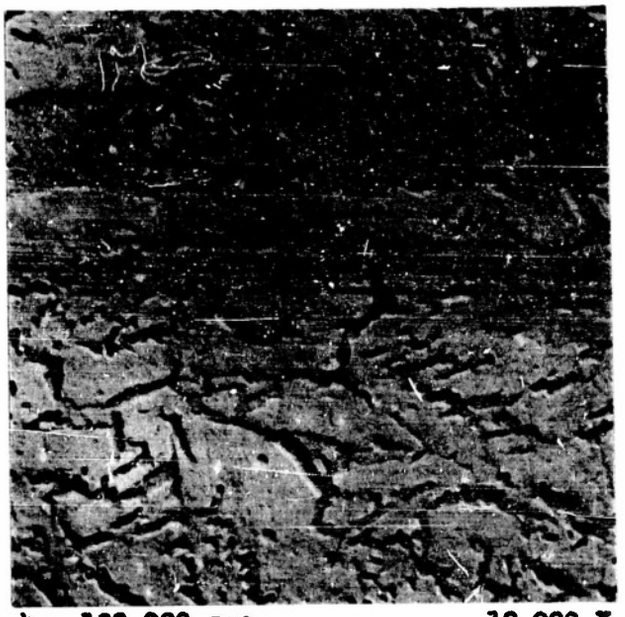


d. 100,000 sec. 12,000 X

Fig. 10 Electron-photomicrographs of bainite; 4340 steel isothermally transformed at 845°F under no applied stress



a. 10,000 sec. 12,000 X

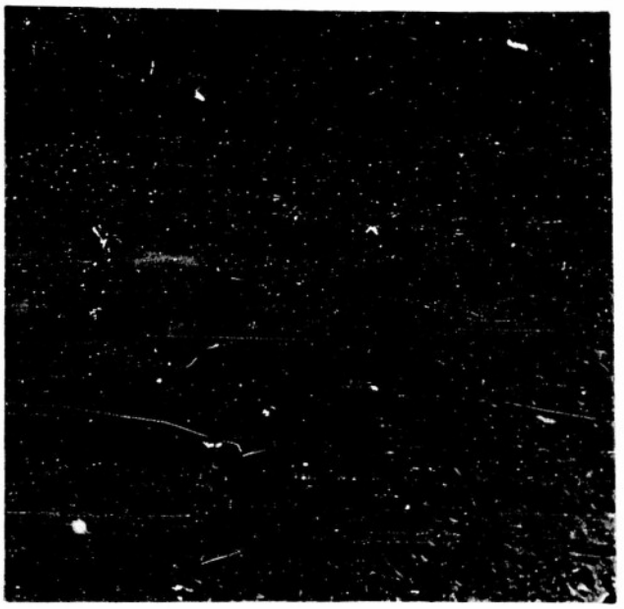


b. 100,000 sec. 12,000 X

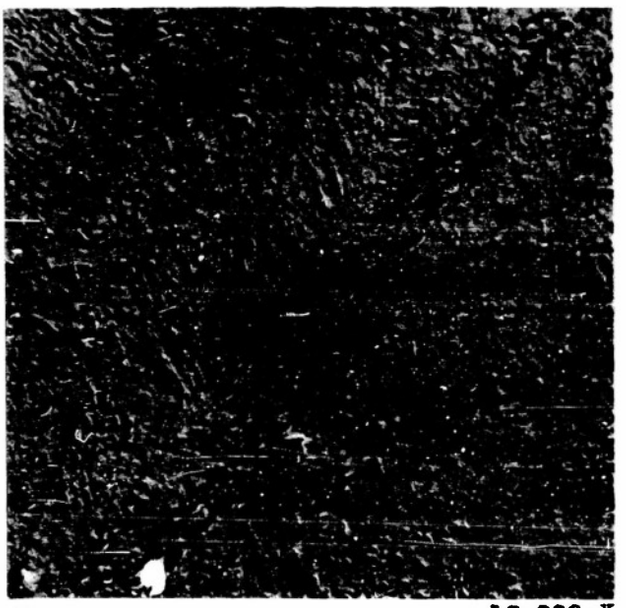
c. 100,000 sec. 12,000 X

d. 100,000 sec. 21,000 X

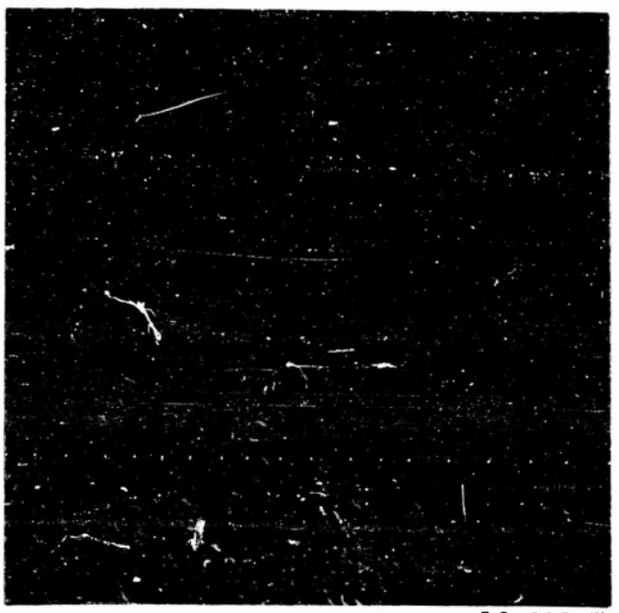
Fig. 11 Electron-photomicrographs of bainite; 4340 steel isothermally transformed at 845°F under 60,000 psi stress



a. 12,000 X



b. 12,000 X

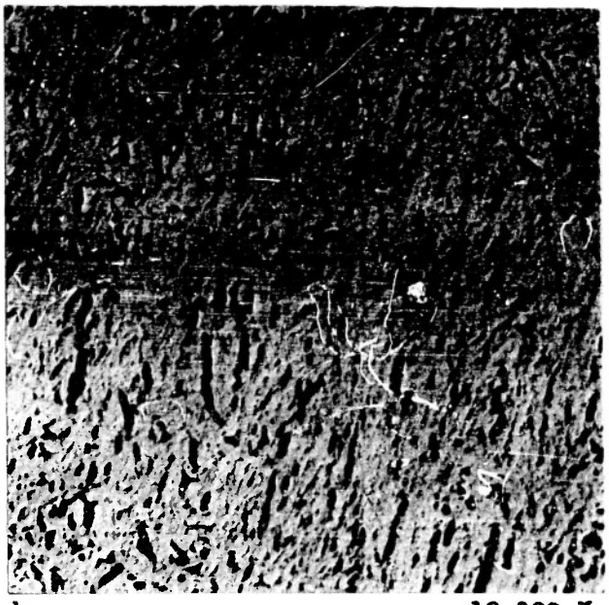


c. 12,000 X

d. 31,000 X

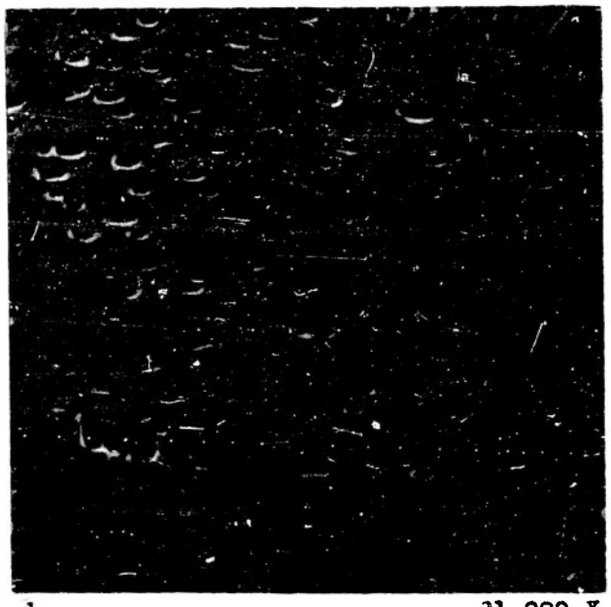
Fig. 12 Electron-photomicrographs of bainite; 4340 steel isothermally transformed at 650°F for 1200 sec. under no applied stress

a. 12,000 X



b. 12,000 X

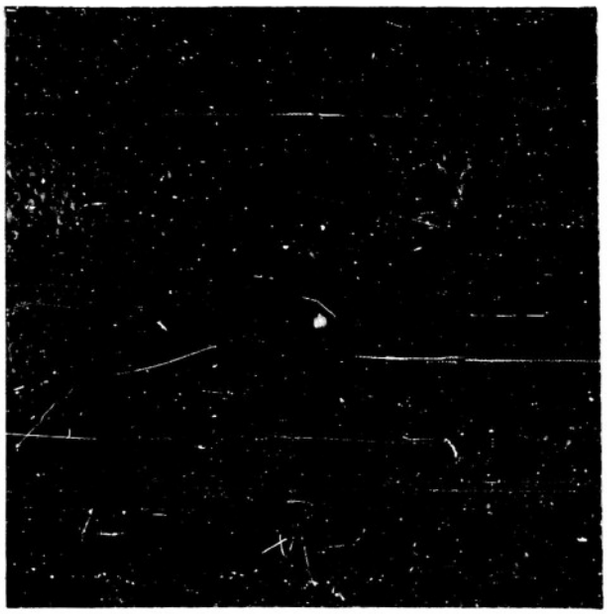
c. 12,000 X



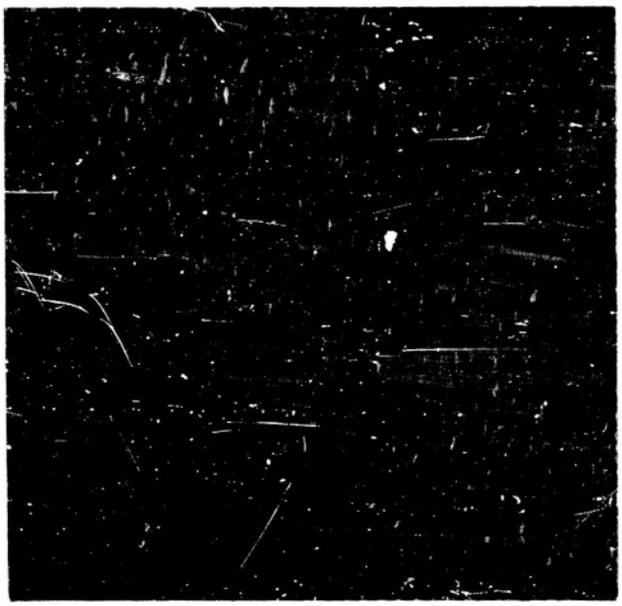
d. 31,000 X

Fig. 13 Electron-photomicrographs of bainite; 4340 steel isothermally transformed at 550°F for 120 sec. under 60,000 psi stress

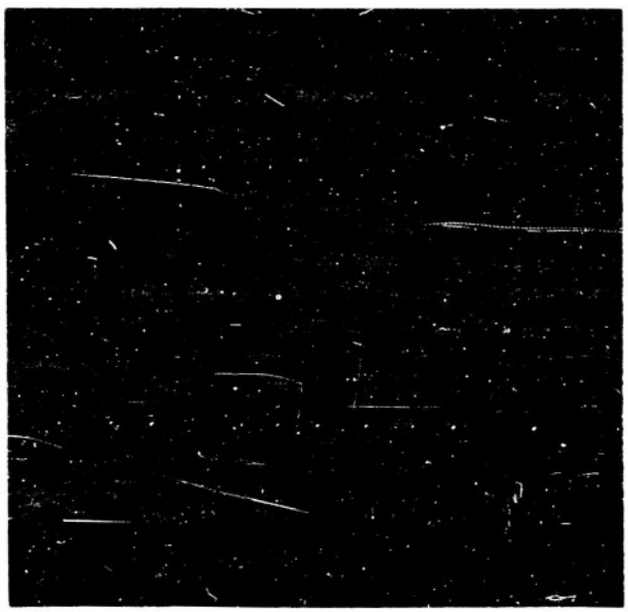
a. 12,000 X



b. 12,000 X

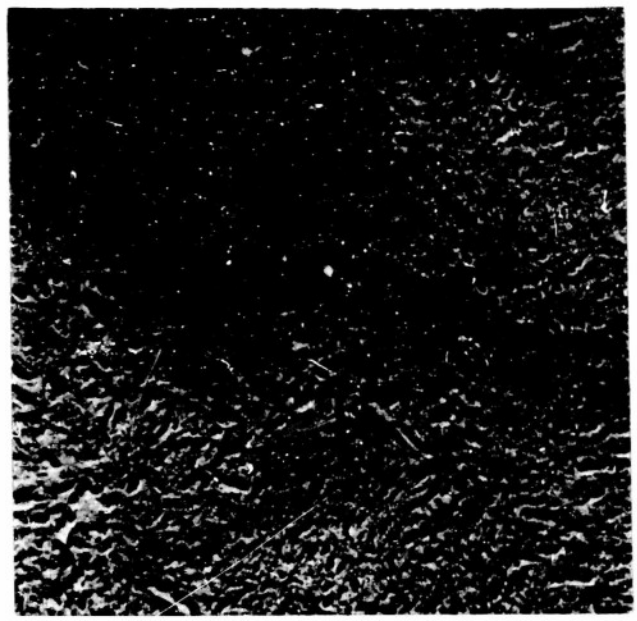


c. 21,000 X

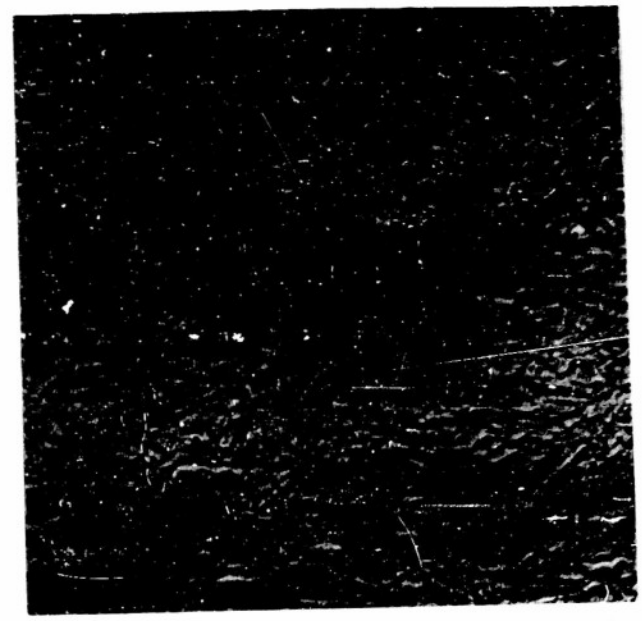


d. 21,000 X

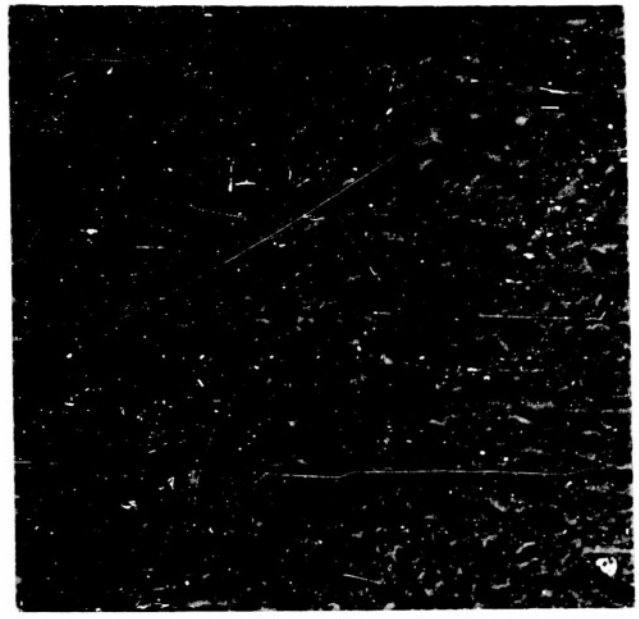
Fig. 14 Electron-photomicrographs of bainite; 1045 steel isothermally transformed at 700°F for 80 sec. under no applied stress



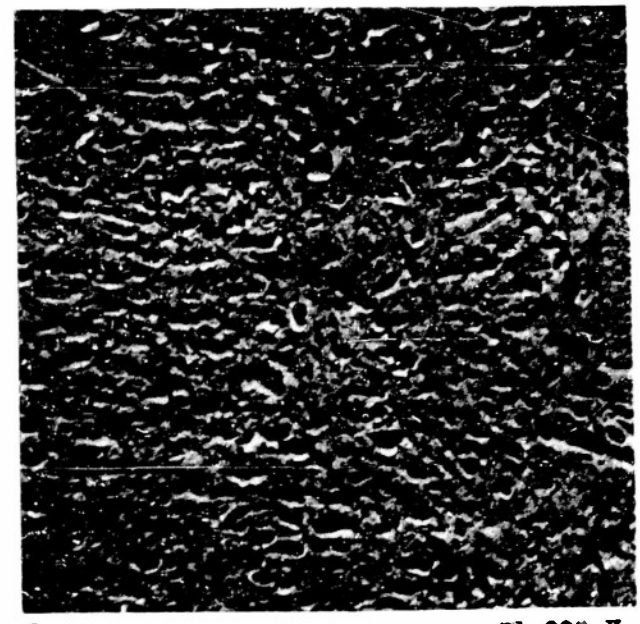
a. 12,000 X



b. 12,000 X



c. 21,000 X



d. 21,000 X

Fig. 15 Electron-photomicrographs of bainite; 1045 steel isothermally transformed at 700°F for 20 sec. under 60,000 psi stress