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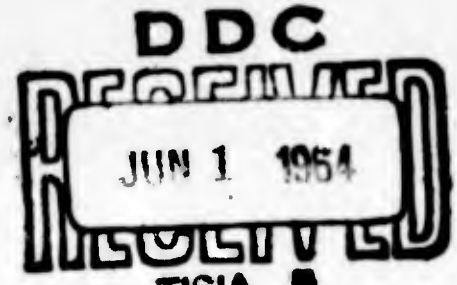
# TECHNOLOGY DEPARTMENT

## PROCESS IMPROVEMENT OF COLUMBIUM (Cb-752) ALLOY

**Phase II Interim Engineering Progress Report**

**1 December 1963 to 31 March 1964**

**Prepared Under Air Force Contract AF-33 (657) -11210**



**UNION CARBIDE CORPORATION -  
STELLITE DIVISION**



**KOKOMO, INDIANA**

PROCESS IMPROVEMENT OF COLUMBIUM (Cb-752) ALLOY

Phase II Interim Engineering Progress Report  
1 December 1963 - 31 March 1964

Manufacturing Technology Division  
Research and Technology Division  
Air Force Materials Laboratory  
Air Force Systems Command  
United States Air Force  
Wright-Patterson Air Force Base, Ohio

Project Nr. 7-9760

(Prepared under Contract AF33(657)-11210 by the Stellite Division, Union Carbide Corporation, Kokomo, Indiana, J.G. Bewley and M. Schussler)

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## FOREWORD

This Interim Technical Progress Report was prepared by the Technology Department, Stellite Division, Union Carbide Corporation under United States Air Force Contract No. AF 33(657)-11210. The work was administered under the direction of Mr. W. E. Smith until about mid-October, 1963, and subsequently Mr. C. S. Cook of the (RTD), Manufacturing Technology Division, Air Force Materials Laboratory, WPAFB, Ohio.

This report describes the results obtained on Phase II of the subject contract and covers the period December 1, 1963 through March 31, 1964. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

The investigation was conducted by J. G. Bewley, Metallurgical Engineer, with M. Schussler acting as Project Coordinator. Others who contributed were R. D. Hess (Mechanical Testing Laboratory), and J. A. Martin (Metallographic Laboratory).

This project is being pursued as a part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. The program encompasses the following technical areas:

- Metallurgy - Rolling, Forging, Extruding, Casting, Fiber, Powder.
- Chemical - Propellant, Coating, Ceramics, Graphite, Nonmetallics.
- Electronic - Solid State, Materials & Special Techniques, Thermionics.
- Fabrication- Forming, Material Removal, Joining, Components.

Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

ABSTRACT

PROCESS IMPROVEMENT OF COLUMBIUM Cb-752 ALLOY

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Approximately 800 pounds of Cb-752 alloy (columbium-10 percent tungsten-2.5 percent zirconium) 1/4-inch thick sheet bar were processed to 0.060-inch thickness, 30-inches width sheets in Phase II. About 200 pounds of sheet in 0.060-, 0.030-, 0.018-, and 0.012-inch gages were produced from this material and furnished in the recrystallized condition to three organizations for urgent requirements.

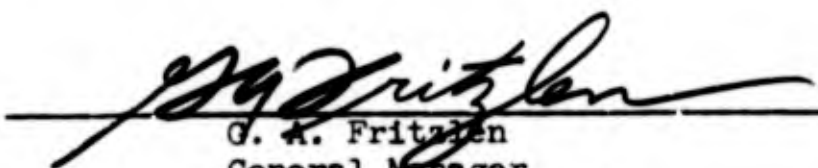
One large sheet was utilized in an addendum to the contract to study the effects on alloy properties of a duplex annealing process. A total of 48 different processing cycles was investigated. A solution treatment at 2800°F, followed by 40 percent reduction by cold rolling, with a final anneal at 2400°F appears to produce the best combination of strength and ductility properties in Cb-752 alloy. This route will be used in the mill fabrication of the remainder of the 0.060-inch thick material to the final sheet gages of 0.030-, 0.018-, 0.012-, and 0.008-inch.

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## SUMMARY

A total of 802 pounds of 1/4-inch Cb-752 alloy sheet-bar was rolled to 0.060-inch thickness sheet during the report period by warm rolling (approximately 250°F) on a 32-inch two-high mill and cold rolling on a 50-inch Sendzimir mill. The material was produced from four heats, one of which represented recycled scrap. The rolling practice followed that developed during Phase I of the contract.

A quantity of 98 pounds of 0.060-inch thick sheet was furnished to Metals and Controls for rerolling to foil on a different contract. An additional quantity of 108 pounds total of Cb-752 alloy sheet was rolled to 0.030-, 0.018-, and 0.012-inch gages, and furnished in the recrystallized condition to Douglas Aircraft and to Martin Company for their requirements on other contracts.

The balance of 0.060-inch thick material is to be processed to the final gages of 0.030-, 0.018-, 0.012-, and 0.008-inch thickness by a solution treatment plus cold working plus aging treatment, referred to as a duplex annealing process. In an addendum to the contract, 48 different duplex annealing processes were investigated for their influence on microstructure, hardness, bend ductility and transition temperature, Olsen cup ductility, tensile properties at room temperature, 1500, 2200, and 2400°F, and creep-rupture properties at 2200°F. Solution temperatures of 2700 and 2800°F for times of 30 and 90 minutes, cold reductions of 20 and 40 percent, and aging temperatures of 2300, 2400, 2500°F for times of 30 and 90 minutes were studied. A 2800°F solution temperature, 40 percent cold reduction, and 2400°F final anneal appeared to result in the best combination of strength and ductility properties; this route will be used in processing the balance of the 0.060-inch thick sheets to final gages.

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## 1. INTRODUCTION

The chief objectives of the contract are:

- 1) to develop methods of producing HAYNES alloy Cb-752 sheet of optimum flatness, gage control, and surface finish
- 2) to establish a reduction annealing schedule which will result in optimized tensile and stress-rupture properties
- 3) to produce a quantity of large panels of Cb-752 sheet by the methods developed
- 4) to evaluate this sheet for flatness, gage control, surface finish and mechanical properties, and to determine the reproducibility of these characteristics in Cb-752 sheet.

As originally conceived, the project involved three phases outlined as follows.

### 1.1 Phase I

In this phase approximately 140 pounds of Cb-752, 1/4-inch sheet-bar was to be reduced to 0.030, 0.018, 0.012, and 0.008-inch thick sheet panels by 10 different processing routes. The sheet so produced was to be inspected for gage variations, flatness, surface finish and shape. Sheet produced by each route was also to be tested for hardness, tensile properties, and stress-rupture properties in two final annealed conditions, stress-relieved at 2000°F and recrystallized at 2200°F. From this investigation an optimum processing route was to be selected based primarily on sheet geometry properties and secondly on mechanical properties.

### 1.2 Phase II

In Phase II approximately 700 pounds of Cb-752, 1/4-inch sheet-bar representing four heats of material were to be reduced to 0.030, 0.018, 0.012, and 0.008-inch thick sheet panels 30-inches wide by 60-inch minimum length. Thickness, flatness and surface finish measurements were to be made on each panel produced. These data were to be tabulated to determine the variation in such properties from sheet to sheet and to establish the degree of reliability with which certain values of these parameters could be met in large Cb-752 sheet panels.

### 1.3 Phase III

Phase III was to involve the determination of room and elevated temperature tensile properties and creep-rupture properties of selected sheet panels of each gage and each heat. These data were to be treated statistically to develop information as to the variation of these properties from sheet to sheet and heat to heat. Guaranteed minimums were also to be established.

#### 1.4 Review of Prior Work

Work in Phase I of the contract was successfully completed as outlined.\* Approximately 112 pounds of Cb-752, 1/4-inch sheet-bar was reduced to the 4 scheduled gages by the 10 reduction annealing schedules. A survey of the geometry of the sheet panels revealed that thickness variation was primarily dependent on rolling parameters rather than reduction annealing schedules; that flatness was primarily a function of the final stretching operation, assuming reasonably good geometry was maintained during final rolling; and that surface finish was almost wholly dependent upon the final pickling operation.

For practical rolling times it was found that reductions should be kept below about 60 to 80 percent between anneals. Room-temperature strength was considerably improved with a stress-relieving anneal at 2000°F as opposed to a recrystallization anneal at 2200°F although a serious degradation of this strength was noted in tensile tests of the stress-relieved material above 2200°F due to dynamic recrystallization which took place during testing. Data on patch weld tests and creep-rupture tests performed on Phase I material, but not completed in time to include in the Phase I report, are discussed in this report and the results given in Section 3.

In addition to the general experimentation of Phase I given previously, one other reduction annealing schedule incorporating a "duplex" anneal was applied to a small sheet of the Cb-752 alloy. The duplex anneal investigated consisted of a solution anneal at 2800°F followed by a cold reduction by rolling of 40 percent and a final anneal of one hour at 2400°F. Tensile tests on sheet given this duplex anneal showed a marked increase in room temperature and 2200°F tensile strength over simple recrystallized material. The tensile properties of the duplex annealed sheet were judged attractive enough to warrant further investigation. As a consequence, a request was made to the contract project engineer and the contract officers for an addendum to the contract to examine more completely this potential strengthening treatment.

#### 1.5 Contract Addendum and Revision

With Air Force approval a decision was made to postpone production and inspection of Cb-752 sheet as scheduled in Phase II until an investigation and optimization of the duplex annealing treatment could be made. This work was estimated to require approximately two months so that the original completion dates of Phases II and III would be set back about two months. At the end of the two months of the addended investigation a decision was to be made as to the optimum reduction-annealing schedule for Cb-752 sheet.

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\* Process Improvement of Columbian (Cb-752) Alloy, Phase I Interim Engineering Progress Report, 1 July 1963 to 30 November 1963, AF Contract AF-33(657)-11210.

Two factors prevented following of the exact plan outlined above. In order to conserve time and since the duplex anneal would affect processing only below 0.060-inch thickness, 1/4-inch thick Cb-752 sheet-bar was rolled to 0.060-inch thickness concurrently with the duplex annealing investigation.

Arrangements had been made by the Air Force to supply Cb-752 sheet produced in Phase II of the contract to several air frame manufacturers and other organizations for use in separate welding, coating, and fabricating contracts. Two of these companies, Martin Company of Denver and Douglas Aircraft Corporation, were tied to tight contract schedules of their own which required finished Cb-752 sheet by the first of March 1964. To meet these requirements in light of the two month contract extension, an additional approximately 100 pounds of 1/4-inch Cb-752 sheet-bar in excess of the original 700 pounds was processed to 0.030, 0.018 and 0.012-inch sheet and shipped to these companies in the recrystallized condition.

With the exception of the deviations described, the Statement of Work and objectives of the contract remain as initially stated.

## 2. REPORT OF PROGRESS

### 2.1 Reduction of 1/4-Inch Thick Sheet-Bar to 0.060-Inch Thick Sheet

As stated in the Introduction the work in Phase II of the contract concerns the reduction of 1/4-inch Cb-752 sheet-bar to 0.030, 0.018, 0.012, and 0.008-inch thick sheet. Toward this goal the approximately 800 pounds of sheet-bar of sizes and weights listed in Table I have been reduced to 0.060-inch sheet during this report period.

#### 2.1.1 Processing to 1/4-Inch Sheet Bar

Some detail about the methods used to produce 1/4-inch sheet-bar is discussed to give a more complete understanding of the production process. The five heats of Cb-752 used to produce the sheet-bar listed in Table I were consolidated as 3-inch diameter ingots, remelted by the electron-beam process to 6-inch diameter and melted a third time to 11-inch diameter ingots by the consumable-arc technique. The 11-inch diameter ingots were sampled, and these samples were analyzed to give the chemical compositions shown in Table II. The arc melted ingots were extruded to rectangular billets which were in turn hot-cold rolled to sheet-bar. Three of the conditioned billets from Heat 52208 are pictured in Figure 1. The 1/4-inch sheet-bar described in Table I was conditioned, square sheared, pickled, and vacuum annealed for one hour at 2500°F prior to being charged into the contract. Sheet-bar of Heats 52206 and 52208 is pictured in Figure 2.

#### 2.1.2 Cold-Rolling Sheet-Bar to 1/8-Inch Thick Sheet

The 17 pieces of 1/4-inch sheet-bar representing 4 heats made from raw material and 1 heat made from reclaimed scrap were rolled on a 2-high rolling mill to 1/8-inch thickness. The mill was equipped with 32-inch diameter by 72-inch wide rolls ground with a 0.012-inch positive crown. To maintain uniform sheet gage the rolls were heated before rolling to induce additional crown by thermal expansion. A typical reduction sequence used to reduce the 1/4-inch sheet-bar to 1/8-inch thickness is shown in Table III.

The gage uniformity and actual per pass reductions were monitored during rolling by taking thickness measurements both along the front edge of the sheet and along the sheet side between passes.

Cold-rolled 1/8-inch sheet of Heats 52206 and 52208 shown in Figure 3 is typical of the appearance of sheet of this thickness. Sheet of good thickness control and adequate flatness was obtained.

### 2.1.3 Conditioning and Annealing 1/8-Inch Sheet

The cold-rolled 1/8-inch sheet was spot buffed to remove scratches and rolled-in dirt. Each sheet was next sheared square to remove any rough or thinned edges. It was then pickled in an HF-HNO<sub>3</sub> solution prior to annealing. The pickled sheet was formed to cylinders of a maximum 20-inches diameter and annealed under vacuum at 2500°F for one hour. A columbium-1 percent zirconium can was employed to contain the sheet during annealing for support and protection against any pickup of dirt or diffusion pump oil during annealing.

### 2.1.4 Sendzimir Mill Rolling to 0.060-Inch Thickness

The 1/8-inch thick Cb-752 sheet was rolled on a ZS-06-50 Sendzimir mill to 0.060-inch thickness. Work rolls of 8-1/2-inch diameter by 50-inch length were used. A roll crown of 0.018-inches was employed consistent with the results obtained in Phase I<sup>(1)</sup> of the contract. Indicated mill reductions per pass were recorded and actual sheet thickness was again monitored with frequent thickness measurements.

Uniform reduction across the sheet width and along the sheet length was obtained by controlling the pressure contour of the rolls (by adjusting eccentric bearings across the top of the back up rolls) and the reduction per pass. Differences in sheet width were compensated for by simply adjusting the pressure contour of the rolls. Although reductions per pass did vary somewhat from sheet to sheet, because of differences in initial sheet contour and width, the schedule presented in Table IV is representative of the reduction sequence employed. Sheets of the 0.060-inch thickness from two heats are shown in Figure 4.

The 0.060-inch thick sheet was rough square sheared, spot conditioned, and pickled. Sheet of the sizes and weights shown in Table V were obtained. This sheet was wrapped and held pending the outcome of the duplex annealing investigation described in Section 2.3.

### 2.1.5 General Discussion and Conclusions on Sheet Processing

Generally the methods employed to reduce the 1/4-inch sheet-bar to sheet were satisfactory. Sheet of satisfactory flatness and gage control was produced. Recovery was quite good; 92 percent at the 1/8-inch sheet stage and 89 percent at the 0.060-inch thick sheet stage, Table VI. No serious problems were encountered anywhere in the process.

Variations in sheet width necessitated frequent adjustment of the pressure contour on the Sendzimir mill rolls, a difficulty which could be overcome with standard width sheets.

### 2.2 Furnishing Sheet to Metals and Controls Company, Douglas Aircraft Corporation and Martin Company

With the incorporation of the duplex annealing investigation into the contract Statement of Work, the original contract schedule for completion of Phases II and III was delayed approximately two months. Thus sheet

to be produced under the contract and supplied to various other Air Force contractors for evaluation was also delayed. Three of the companies were involved in fixed time or fixed fee contracts or tight schedules of their own which could not tolerate late material delivery. To fill this immediate need of Metals and Controls, Douglas Aircraft and Martin Company, an additional approximately 100 pounds of Cb-752, 1/4-inch sheet-bar was put into the contract and reduced to 0.060, 0.030, 0.018, and 0.012-inch thick sheet.

#### 2.2.1 Metals and Controls Requirement

The Metals and Controls Company, Attleboro, Massachusetts, required approximately 100 pounds of Cb-752 sheet reroll stock for rolling to 0.002- and 0.006-inch thick foil. This foil was to be used in coating, brazing, and welding evaluation by 651G contractors in a tightly scheduled program. Consequently, 83 pounds of 0.060-inch Cb-752 sheet was shipped to Metals and Controls on January 1, 1964 followed by 15 pounds on February 4, 1964. Since this material was for reroll stock, no attempt was made to apply a duplex or optimized annealing treatment. The sheet was given a simple recrystallization anneal of one hour at 2300°F. Microstructure of Cb-752 sheet in this condition is shown in Figure 5. The sizes and weights of sheet shipped are given in Table VII.

#### 2.2.2 Douglas Aircraft Requirement

Douglas Aircraft required approximately 50 pounds of finished Cb-752 sheet of gages 0.012- and 0.018-inch. Their needs were of an immediate nature which could not be delayed until the completion of the duplex annealing investigation. To fill these needs, Cb-752 sheet of Heats 52165 and 52227 was rolled to 0.012- and 0.018-inch thickness on the Sendzimir mill, flash pickled and vacuum annealed for one hour at 2300°F. The annealed sheet was stretcher leveled, sheared square and inspected for gage variation, flatness and surface finish. The sheet was shipped in the recrystallized condition, Figure 6, a very ductile condition of appreciably lower strength than material in the duplex annealed condition, see Section 2.3.

Results of thickness measurements made on the sheet sent to Douglas are given in Table VIII. The average gage differed from the nominal or target gage in most cases by less than 0.0005-inch. Part of the sheet sent to Douglas was produced from excess sheet which had remained from Phase I of the contract. This sheet was rerolled and annealed as described above and this explains the number of different sizes, (see Table VII) of sheets sent to Douglas. Approximately 46 pounds of Douglas' requirement was shipped on March 5, 1964 and the remainder (approximately 6 pounds) on March 24, 1964.

#### 2.2.3 Martin Company Requirements

For reasons similar to those given for Douglas and Metals and Controls, Martin required delivery of Cb-752 sheet before delivery of duplex annealed sheet would have been possible. To comply with Martin's needs, 0.060-inch Cb-752 sheet of Heat 52227 was rolled on the Sendzimir

mill to 0.012, 0.018, and 0.030-inch thickness. This sheet was next flash pickled, vacuum annealed for one hour at 2300°F and stretcher-leveled. This sheet was subsequently sheared to the sizes given in Table VII. Figure 7 pictures the microstructure of the annealed sheet. Very good gage uniformity was achieved in these large sheets; thickness data presented in Table VIII show close conformance to target thicknesses. Excellent sheet of the sizes and weights shown in Table VII was shipped to Martin Company, Denver, Colorado on March 5, 1964. This sheet again was in the recrystallized condition rather than the optimized duplex annealed condition described in Section 2.3.

### 2.3 Duplex Annealing Investigation

As reported in the Phase I report and described in the Introduction to this report, duplex anneals involving a high temperature solution anneal, followed by a cold-rolling reduction between 20 and 40 percent, and a final aging anneal can be employed to significantly increase the room and elevated temperature strength of Cb-752 sheet. This treatment showed such promise in work in Phase I that approval of the contract officials was sought and obtained to add to the original Statement of Work of the contract an addendum covering an investigation of temperature, time at temperature and percent reduction variations of the duplex treatment. A time extension of two months was granted to accomplish the objectives of this investigation outlined as follows:

1. Investigate the feasibility of a duplex annealing treatment as a production process.
2. Determine the optimum combination of annealing temperatures and times and percent cold reduction in terms of improved room and elevated temperature strength.
3. Determine the effects of this optimum duplex annealing treatment on the bend and Olsen cup ductility and on the bend transition temperature.

To accomplish these objectives the investigation demonstrated schematically in Figure 8 was undertaken.

#### 2.3.1 Reduction of Sheet to Gage

A sheet of Cb-752 Heat 52206 of size 0.060 by 30-3/4 by 59-1/2-inch, weighing 37.70 pounds was rolled to 0.040-inch thickness by 30-3/4-inch width by 90-inch length. This sheet was cut into four equal pieces each identified as Piece No. 1, 2, 3, or 4. These pieces were flash pickled and annealed in vacuum as shown below.

<u>Piece Identification</u>	<u>Size</u>	<u>Heat-Treatment</u>
1	0.040 x 30-1/2 x 22.5	One-half hour at 2700°F
2	"	Two hours at 2700°F
3	"	One-half hour at 2800°F
4	"	Two hours at 2800°F

Microstructures of the sheet annealed for one-half hour at 2700 and 2800°F are shown in Figure 9. Some grain growth has occurred in the short time anneals and this grain growth was only slightly more pronounced in the longer anneals, not shown.

Each of the solution annealed sheets was sheared into two-pieces, one piece of each original sheet being rolled on the Sendzimir mill to 0.032-inch thickness and the other piece of each sheet being rolled to 0.024-inch for 20 and 40 percent reduction, respectively. Eight sheets resulted, each approximately 15-1/2-inch by 30-inch in size.

Each of the eight pieces was cut into six equal size samples with one sample from each original sheet being given final aging treatments as shown below.

<u>Designation</u>	<u>Annealing Treatment</u>
A	One-half hour at 2300°F
B	One-half hour at 2400°F
C	One-half hour at 2500°F
D	One and one-half hour at 2300°F
E	One and one-half hour at 2400°F
F	One and one-half hour at 2500°F

Following the processing outlined above, 48 sheet samples, each of approximate size 4-1/2 by 14-inches were produced representing four solutioning treatments, two different cold reductions, and six aging treatments.

### 2.3.2 Sampling

Each of the 4-1/2 by 14-inch sheets was sheared to tensile, bend, Olsen cup test and metallographic samples as shown in Figure 10. Eight tensile blanks, 4 bend specimens and one 3 by 3-inch Olsen cup specimen were sheared from each sheet.

According to the designations given the sheet for the different solution anneals and the final anneals, a code was assigned each of the 48 sheets, consisting of a combination of numbers and letters; for example, sheet number 4B<sub>1</sub>. The first numeral refers to the solution annealing temperature, the middle letter to the final aging treatment, and the final subscript to the percent reduction; either 1 for 20 percent reduction (0.032-inch sheet) or 2 for 40 percent reduction (0.024-inch sheet). The designations for the solution and final anneals have been defined above.

### 2.3.3 Testing

Each sheet was tested for hardness, Olsen cup ductility, room temperature and -320°F bend ductility, and room temperature tensile properties. Samples of each sheet were also examined metallographically. Based on the results of these evaluating tests, sheets in 20 conditions were selected to be tested for 2200°F tensile properties (see Figure 8 for a schematic outline of testing). Next, twelve sheets were selected from these data for tensile tests at 1500 and 2400°F. Finally five sheets judged best by the above tests and representing five unique duplex annealing treatments were selected for creep-rupture tests at 2200°F.

#### 2.3.3.1 Hardness Tests

Superficial Rockwell B hardness tests were performed on sheet samples in each of the 48 duplex annealed conditions. The hardness results shown in Table IX reveal variations ranging from  $R_b$  87 to  $R_b$  92.5. Generally the sheet cold reduced 20 percent exhibited a higher hardness than sheet cold reduced 40 percent after the solution anneal. The only other trend readily apparent is the slightly greater hardness of sheet given the 2400°F aging treatment.

#### 2.3.3.2 Metallographic Examination

To determine the approximate recrystallization temperature of Cb-752 sheet given solution anneals at 2700 and 2800°F and cold reduced 20 and 40 percent, samples of sheet in these conditions were given final anneals for one hour at six temperatures ranging between 2100 and 2600°F. Shown in Figure 11 through 18 are photomicrographs of sheet in each solution annealed and cold reduced condition after final anneals of one hour at temperatures of 2100, 2300, and 2600°F.

Two general statements can be made about the recrystallization characteristics of the sheet. Sheet cold reduced 20 percent to 0.032-inch did not recrystallize in the 2300°F anneal but in nearly every case recrystallized completely during the final anneal at 2600°F. Sheet cold reduced 40 percent to 0.024-inch in most cases showed no recrystallization at 2100°F, partial recrystallization at 2300°F and full recrystallization at 2600°F.

The precipitate amount, particle size, and distribution varied greatly both with solutioning treatment and aging temperature. Longer solutioning times and the higher solutioning temperature apparently favored the formation of a heavy precipitate. This precipitate remained distributed as bands of particles along the "work lines" of the sheet after the 2100°F anneal but tended to agglomerate into more massive, randomly distributed particles during the 2600°F anneal. The grain boundaries of the sheet final annealed at 2600°F appear to have thickened, suggesting possible grain boundary segregation of the precipitate.

A note of caution must be observed concerning strict interpretation of the photomicrographs shown in Figures 11 through 18 and Figures 19 through 25 as well. The structure observed with both the light and electron microscope was found to be extremely sensitive to the amount of etching. The amount and particle size of observed precipitate was especially dependent on the degree of etch.

In Figures 19 through 25 are presented light and electron micrographs of Cb-752 sheets given certain of the actual duplex anneals investigated in this study. For purposes of comparison the microstructures shown can be divided into three distinct groups based on precipitate morphology.

Figures 19 and 23 show structures relatively free from all but scattered precipitate particles. These particles are randomly distributed in the matrix leaving the grain boundaries free of any appreciable precipitate. Sheets 2A<sub>2</sub> and 3F<sub>2</sub>, exhibiting this type of structure, had in common a ductile Olsen cup failure but differed considerably in room temperature ultimate strength.

Sheet microstructure shown in Figures 20, 21, and 24 have in common a heavy grain boundary precipitate. Sheet of Figure 20 has in addition a heavy matrix precipitate, and in contrast to the sheet of Figures 21 and 24 exhibits very little recrystallization. This latter fact perhaps explains the unusually high room temperature and 2200°F ultimate strengths of this sheet.

The grain boundary precipitate of Figure 21 is more spherical in nature than Figure 24 and less continuous. This may be a consideration in the brittle type Olsen cup test exhibited by sheet 4E<sub>1</sub> of Figure 24. When compared on other terms such as room temperature ultimate strength, sheet 2B<sub>1</sub> of Figure 21 and 4E<sub>1</sub> of Figure 24 seem to behave similarly.

Microstructures of sheets 3B<sub>1</sub> and 4E<sub>2</sub> shown in Figures 22 and 25 also appear similar in many respects. Both sheets exhibit an intermediate amount of matrix precipitate distributed in bands across individual grains. While the electron micrographs of both sheets show some precipitate, the particles are agglomerated so that there is no hint of any continuous grain boundary network. This is consistent with the observed ductile Olsen cup tests of these two sheets. Sheets 3B<sub>1</sub> and 4E<sub>2</sub> were also almost exact duplicates in terms of measured ultimate strength both at room temperature and at 2200°F.

An interesting comparison can be made between Figures 24 and 25 which show microstructures of two sheets which received the same solution and aging anneals but different percents cold reduction prior to the final or aging anneal. The precipitate in sheet 4E<sub>1</sub>, Figure 24, is distributed primarily along the grain boundaries in a series of spherical and elongated particles. The precipitates in sheet 4E<sub>2</sub>, Figure 25 on the other hand is distributed along what appears to be remnants of cold work lines, leaving the grain boundaries relatively clean. A semicontinuous grain boundary network of precipitate particles such as displayed by sheet 4E<sub>1</sub>, Figure 24, offers a logical explanation for the otherwise unexplained brittle Olsen cup failure exhibited by some of the duplex annealed sheets.

### 2.3.3.3 Olsen Cup Tests

Olsen cup tests were performed on 3 by 3-inch samples of sheet in each of the 48 annealed conditions. Cup depth and rupture stress were recorded on a Riehle tensile apparatus. The results are given in Table IX. Cup depths ranged from 0.160-inch to 0.443-inch. Failures were of two types: 1) a ductile failure in which the rupture occurred in a radial line near the top of the cup and didn't extend beyond the cup, and 2) a brittle failure in which a crack initiated at the top of the cup or elsewhere, and propagated into the undeformed area surrounding the cup. Both brittle and ductile Olsen cup failures are pictured in Figures 26 and 27.

Out of a total of 48 annealed conditions, sheet in only eight conditions exhibited a brittle type failure. Of particular significance is the fact that every Olsen cup specimen given the 2800°F two hour solution anneal and 20 percent cold reduction failed in a brittle manner, regardless of the final aging anneal. All sheets receiving a 40 percent cold reduction showed ductile behavior in the cup tests, regardless of the solution and aging temperatures and times.

### 2.3.3.4 Bend Tests

Specimens of sheet in each annealed condition were tested at room temperature around a 0.030-inch radius bar and around a 0.030, a 0.060 and in some cases a 0.120-inch radius pin at -320°F. Tests at both temperatures were performed on 1/2 by 1-1/2-inch specimens. Load was applied at the rate of 2 inches/minute with a Riehle tensile apparatus. Specimens were tested "as sheared" with no special edge preparation. Tests were conducted on specimens submerged in liquid nitrogen to meet the -320°F temperature requirements. Specimens which exhibited any crack visible to the unaided eye were considered "failed" in determining the minimum bend radius. All specimens were bent so that the bend radius was in the transverse direction. Bend test results are listed in Table IX.

All specimens passed the room temperature bend around the 0.030-inch radius pin. Specimens tested at -320°F exhibited ductilities ranging from successful bends around 0.060-inch diameter pins to failure in bends around 0.240-inch diameter pins. On the average, specimens representing 20 percent reduction between anneals behaved less ductile in -320°F bend tests than the 40 percent cold reduced specimens. This difference in behavior might be attributed in part to the different specimen thickness; a bend around a 0.060-inch diameter pin comprised a bend slightly sharper than 2T for the 0.032-inch material and slightly greater than 2T for the 0.024-inch thick sheet.

### 2.3.3.5 Tensile Tests

Specimens with a 0.250-inch width by 1-inch length gage section were machined from the 1-1/16 by 3-1/16-inch specimen blanks for use both in room and elevated temperature tensile tests.

#### 2.3.3.5.1 Room Temperature Tensile Tests

Tests were conducted at room temperature on the Riehle tensile machine employing a controlled strain rate of 0.005-inch/inch/minute to 0.6 percent offset yield strength, and 0.05 inch/inch/minute thereafter to failure. Duplicate specimens of each annealed condition were tested. The room temperature tensile properties are shown in Table X. Values of room temperature yield strength ranged from 57,600 to 71,800 psi, ultimate strength from 81,000 to 92,700, and elongation from 22 to 29 percent. As was expected, the room temperature yield and ultimate strength was found to decrease while the elongation increases with an increase in the final annealing temperature. Also, in most cases material given the one-half hour final anneals was stronger and less ductile than material annealed for one and one-half hour.

#### 2.3.3.5.2 Elevated Temperature Tensile Tests

Elevated temperature tensile tests were conducted on an Instron tensile machine at a constant cross-head speed of 0.05 inch/inch/minute to failure. Tests were conducted in a vacuum of better than  $5 \times 10^{-6}$  millimeters of mercury. Temperature was supplied by a Marshall furnace equipped with tantalum heating elements and controlled by a platinum, platinum-rhodium thermocouple. Specimen temperature was measured via such a thermocouple attached directly to the specimen test section. Duplicate tests were performed at 2200°F on specimens in 20 selected duplex annealed conditions. Duplicate tests were performed at 1500 and 2400°F on specimens of sheet in 12 selected conditions. The results appear in Table XI.

At 2200°F, values of yield strength ranged from 22,000 to 32,600 psi, ultimate strength from 30,000 to 36,900 psi, and elongation from 30 to 72 percent. As was anticipated, sheet given the lower final annealing treatments was stronger but less ductile at 2200°F than sheet given the higher temperature final anneals. Solution anneals at 2800°F appear slightly superior in terms of improved 2200°F tensile strength, e.g. the high strength of sheet 4A<sub>2</sub> versus 2A<sub>2</sub>, Table XI. The extremely high elongation of all the duplex annealed material at 2200°F is worthy of note.

Tensile properties of duplex annealed sheet at 1500 and 2400°F are also presented in Table XI. The yield strength of this sheet was found to vary from about 35,000 to 45,000 psi at 1500°F and 18,000 to 22,000 psi at 2400°F. Less variation was found in the ultimate strength, this property ranging from about 55,000 to 62,000 psi at 1500°F and 23,000 to 27,000 psi at 2400°F. The low elongation at 1500°F, 6 to 12 percent, is in sharp contrast to the 60 to 90 percent elongation displayed by the sheet specimens at 2400°F. The low 1500°F elongation is attributed to a strain aging reaction known to occur in most columbium-base alloys in the temperature range of about 1200 to 1800°F.

### 2.3.3.6 Creep-Rupture Tests

Creep-rupture tests were performed on specimens of the same design as those used in the room and elevated temperature tensile tests. Tests were conducted in hot-wall vacuum furnaces under a vacuum of better than  $7 \times 10^{-5}$  and typically  $4 \times 10^{-5}$  millimeters of mercury. For additional insurance against contamination, each specimen gage section was flash pickled and carefully wrapped with several layers of 0.002-inch Cb-752 foil.

The foil could be bent flat upon itself after extended tests at 2200°F, indicating adequate oxidation protection. Bend tests on the ruptured specimen test sections substantiated the low amounts of oxygen contamination.

The creep-rupture frames were equipped with self adjusting motors which raised the upper specimen pull-bar to maintain a constant lever arm ratio during specimen elongation. Creep was measured by a dial gage attached to the upper pull-bar.

The creep-rupture properties so determined are presented in Table XII.

The tests, conducted at 2200°F under 15,000 psi stress resulted in rupture lives ranging from 12.8 to 37.9 hours. Total elongation varied from 36 to 100 percent while the reduction in area of the specimen gage section ranged from 60 to 78 percent. Since the test rigs were not equipped with extensometers, only gross creep could be measured with any degree of accuracy. Included in Table XII are measured times for five percent elongation. Because of the high stress ( $\sim$  one-half the yield strength at 2200°F) employed, the creep rate of the specimens was fairly rapid and therefore of only limited value in determining the creep resistance of the alloy. Creep-rupture tests will be performed in Phase III of the contract to better characterize the creep properties of duplex annealed Cb-752 sheet.

None of the duplex annealed sheet tested displayed a rupture life at 2200°F clearly superior to the other conditions, and therefore the rupture properties were not considered a major basis for selection of the optimum duplex annealing treatment.

### 2.3.4 Summary of Results

Variations in hardness of Cb-752 sheet in different duplex annealed conditions were slight, ranging from Rb 87 to Rb 92.5.

The microstructure of duplex annealed sheet varied greatly with solutioning temperature, percent cold reduction, and aging temperature. Partial recrystallization was observed in a majority of the duplex annealed sheets. The precipitate quantity, shape, size and distribution differed with percent reduction and final annealing treatment. Heavy grain boundary precipitate was associated with brittle Olsen cup test failures.

Sheet in all duplex annealed conditions passed the 0.030-inch radius bend test at room temperature. At  $-320^{\circ}\text{F}$  sheet samples in some duplex annealed conditions were successfully bent around a 0.030-inch radius while others failed bends around a 0.120-inch radius.

Values of room temperature yield strength, ultimate strength and elongation were obtained which ranged from 57,600 to 71,800 psi, 81,000 to 92,7000 psi and 22 to 29 percent, respectively. Figures 28 to 29 which show bar graphs of the room temperature ultimate tensile strength of the duplex annealed sheet permit a comparison of the effects on this property of the annealing variables. One of the most obvious conclusions which can be drawn from these figures is that the highest room temperature ultimate tensile strength was achieved in nearly every case with the solution anneal of  $2800^{\circ}\text{F}$  for two hours.

In general the room temperature tensile strength decreased with increasing final aging temperature. The most notable exceptions were conditions 4C<sub>1</sub> and 4F<sub>1</sub> of Figure 28. The unusually high strength exhibited by material in these two conditions was unfortunately accompanied by a brittle type Olsen cup test failure. The material cold reduced 40 percent prior to the aging anneal displayed somewhat lower room temperature tensile strength than material cold reduced 20 percent, Figure 29 versus 28, although some individual conditions proved to be exceptions. Sheet in a number of duplex annealed conditions exhibited decidedly improved room temperature tensile strength and on this basis as well as ductility tests, twenty of the conditions were selected for tensile tests at  $2200^{\circ}\text{F}$ .

The  $2200^{\circ}\text{F}$  ultimate tensile strength of Cb-752 sheet in the twenty selected duplex annealed conditions is presented for easy comparison in bar graphs of Figures 30 and 31. Modest to impressive increases were realized in the  $2200^{\circ}\text{F}$  tensile strength of Cb-752 sheet through the duplex annealing treatments; gains ranged from about 1,000 psi to 8,000 psi above the typical 29,000 psi ultimate strength of recrystallized Cb-752 sheet at this temperature. Elongation of the duplex annealed sheet at  $2200^{\circ}\text{F}$  was excellent in all cases.

Elevated temperature tensile tests of duplex annealed Cb-752 sheet at 1500 and  $2400^{\circ}\text{F}$  revealed attractive strength levels at both 1500 and  $2400^{\circ}\text{F}$ , Table XI. Elongation on the other hand, while very good at  $2400^{\circ}\text{F}$  was relatively low at  $1500^{\circ}\text{F}$  ranging from 6 to 11 percent. This low elongation at  $1500^{\circ}\text{F}$  is attributed to a strain aging effect and is characteristic of columbium-base alloys.

Figures 32, 33, and 34 present a comparison of the yield strength, ultimate strength and elongation, respectively, of recrystallized and duplex annealed Cb-752 sheet. It should be noted that the tensile data shown in Figures 32, 33, and 34 are for duplex annealed sheet of Heat 52206 from the present investigation and recrystallized sheet of Heat 52165 from the Phase I investigation.

The yield strength of the duplex annealed sheet is substantially superior up to  $2200^{\circ}\text{F}$ , but at  $2400^{\circ}\text{F}$  the yield strength of the duplex anneal material approaches that of the recrystallized sheet. A similar trend is observed with the ultimate strength, although sheets in some duplex annealed conditions displayed values of ultimate strength at

1500°F below the recrystallized sheet, Figure 33.

The tensile elongation of the Cb-752 sheet is not significantly affected by the duplex anneal except in the intermediate temperature range. As seen in Figure 34, the elongation at 1500°F of duplex annealed sheet 4E<sub>2</sub>, while 2 percent lower than recrystallized sheet, is still an adequate and acceptable 11 percent. Thus no problems are anticipated concerning intermediate temperature ductility of Cb-752 sheet given selected duplex annealing treatments.

The creep-rupture results presented in Table XII are not conclusive evidence of the effects of the duplex annealing treatments on the creep-rupture properties of Cb-752 sheet. Such a determination must await the more comprehensive investigation of creep and rupture properties of Cb-752 sheet scheduled in Phase III of the contract.

### 2.3.5 Conclusions

1. The room and elevated temperature tensile strength of Cb-752 sheet can be substantially and significantly improved through the use of duplex annealing treatments involving a high temperature penultimate solution anneal, cold reduction by rolling, and a final aging anneal.
2. These strength increases can be gained without any serious degradation of bend ductility, ductile to brittle transition, Olsen cup ductility, or room and elevated temperature tensile elongation.
3. The duplex annealing treatment can be applied with no difficulty to Cb-752 sheet and is not detrimental to sheet gage control, flatness or surface finish.
4. In summary, the duplex annealing treatment appears to be a feasible and attractive method of increasing the room and elevated temperature tensile strength of Cb-752 sheet without detracting from sheet fabricability.

### 2.3.6 Recommendations

It is recommended that a duplex annealing treatment consisting of a penultimate solution anneal at 2800°F followed by 40 percent cold reduction and an aging anneal at 2400°F, corresponding to the treatment given sheet 4E<sub>2</sub>, be applied to the balance of Cb-752 sheet in Phase II of the contract to improve the room and elevated temperature tensile properties of the material.

It is recommended that, with the exception of this new annealing treatment, Phases II and III of the contract be continued as outlined in the Introduction, Section 1.0.

### 3. UNREPORTED PHASE I DATA

Work accomplished in Phase I of the contract and summarized in the Phase I report concerned an investigation of the effects of various reduction-annealing schedules on the flatness, surface finish, gage uniformity and mechanical properties of Cb-752 sheet. Some tests hadn't been completed when the Phase I report was issued, and thus the results were not included. These unreported test results including creep-rupture tests and cross-patch weld tests are given and analyzed in the following sections.

#### 3.1 Phase I Creep-Rupture Tests

Sheet specimens having a 0.250-inch width by 1-inch length gage section representing the 10 reduction annealing schedules investigated in Phase I and in two final annealed conditions were tested in a cold wall vacuum furnace at 2400°F and under a 10,000 psi stress. Tantalum foil was wrapped around the test sections to prevent contamination. Pressures were maintained below  $5 \times 10^{-5}$  millimeters of mercury while temperatures were controlled to within  $\pm 25^\circ\text{F}$  with a platinum, platinum-rhodium thermocouple control.

The rupture life, elongation and minimum creep rate values are presented in Table XIII. The considerable variation in rupture life and creep rate precludes any firm conclusions being drawn from the data and only a few trends are apparent. On the whole, the stress relieved (one hour at 2000°F) sheet specimens exhibited a longer rupture life and a smaller creep rate. However, sheet cold reduced more than about 90 percent prior to anneal suffered a deterioration in these properties, see results for sheets A21 and A221 in the stress-relieved condition.

The alloy will be much better characterized as to creep-rupture properties in Phase III of the contract.

#### 3.2 Cross-Patch Weld Tests

To check on the weldability of Cb-752 sheet produced by each of the 10 reduction annealing schedules and to determine if there was any susceptibility to thermally induced weld or base metal cracking, 4 by 4-inch samples of sheet were sent to McDonnell Aircraft Corporation for patch weld tests. In this test, Heliarc weldments were made on sheet under an argon atmosphere. The "bead on plate" type of welds were made by rotating a stage on which the sheet was resting to obtain the circular pattern. Cross welds were then made by manually moving the torch across the diameter of the circle. Pictured in Figure 35 are some patch weld specimens of Cb-752 sheet showing the weld pattern.

This type of welding evaluation is considered a severe test of the weldability of refractory metal sheet. Although the sheet specimens aren't restrained during welding, relatively large stresses are set up at the point where the cross welds meet at the center of the circle and where the cross welds meet the circle circumference.

The welded specimens were subjected to visual, dye penetrant and X-ray inspection and found to be free of any cracks or tears. The small holes seen in the weld seams in Figure 35 were caused when slight sheet warpage brought that particular portion of the sheet too close to the torch, resulting in a "burn-through".

#### 4. FUTURE WORK

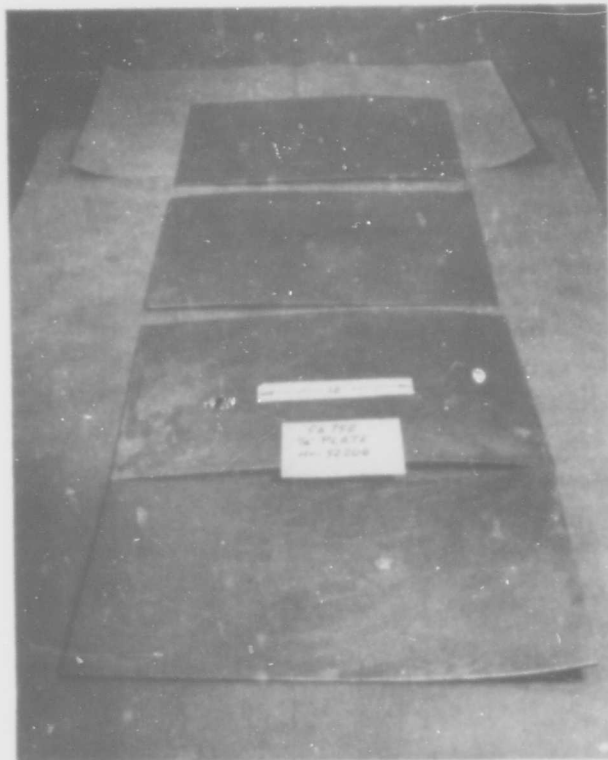
Upon approval by Air Force personnel, the optimum duplex annealing treatment recommended in Section 2.3.6 will be applied to the approximately 480 pounds of 0.060-inch Cb-752 sheet in processing this sheet to final thicknesses of 0.030-, 0.018-, 0.012-, and 0.008-inch. This sheet will be measured for flatness, thickness variation and surface finish as described in the Introduction. The sheet will also be evaluated for mechanical properties as well as weldability and thermal stability.



Figure 1  
Neg. No. C-3563-2

Figure 1: Extruded, conditioned and annealed Cb-752 billets, Heat 52208.

Neg. No. C-3680



Neg. No. C-3681



Figure 2: Conditioned 1/4-inch thick Cb-752 sheet-bar, Heats 52206 and 52208.

Neg. No. C-3699



Neg. No. C-3698

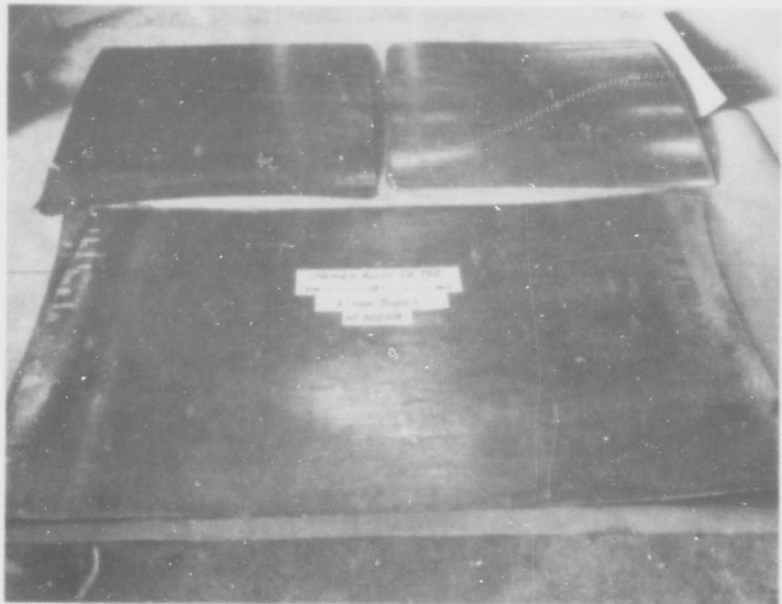


Figure 3: As-cold-rolled 1/8-inch thick Cb-752 sheet, Heats 52206 and 52208.

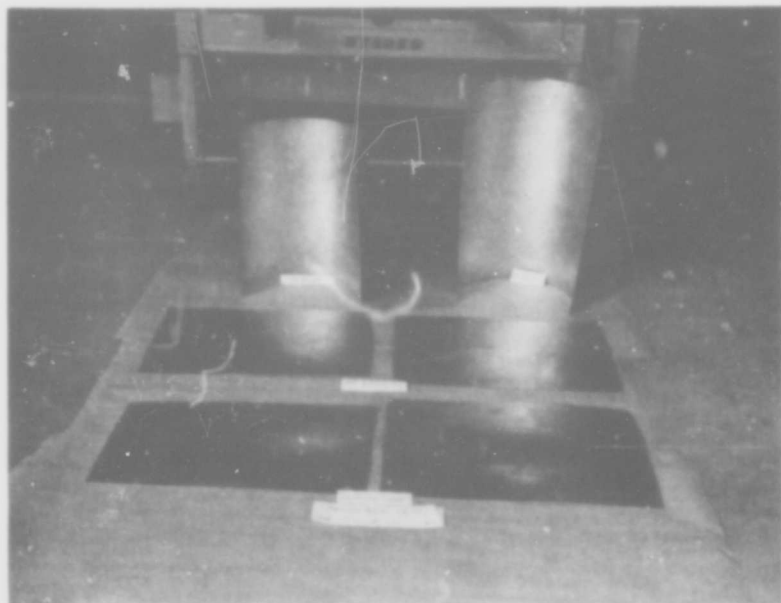


Figure 4  
Neg. No. C-3805

Figure 4: Cold-rolled and annealed 0.060-inch thick Cb-752 sheet, Heats 52165 and 52227. Sheet in back still retains the curved shape from the annealing "set".

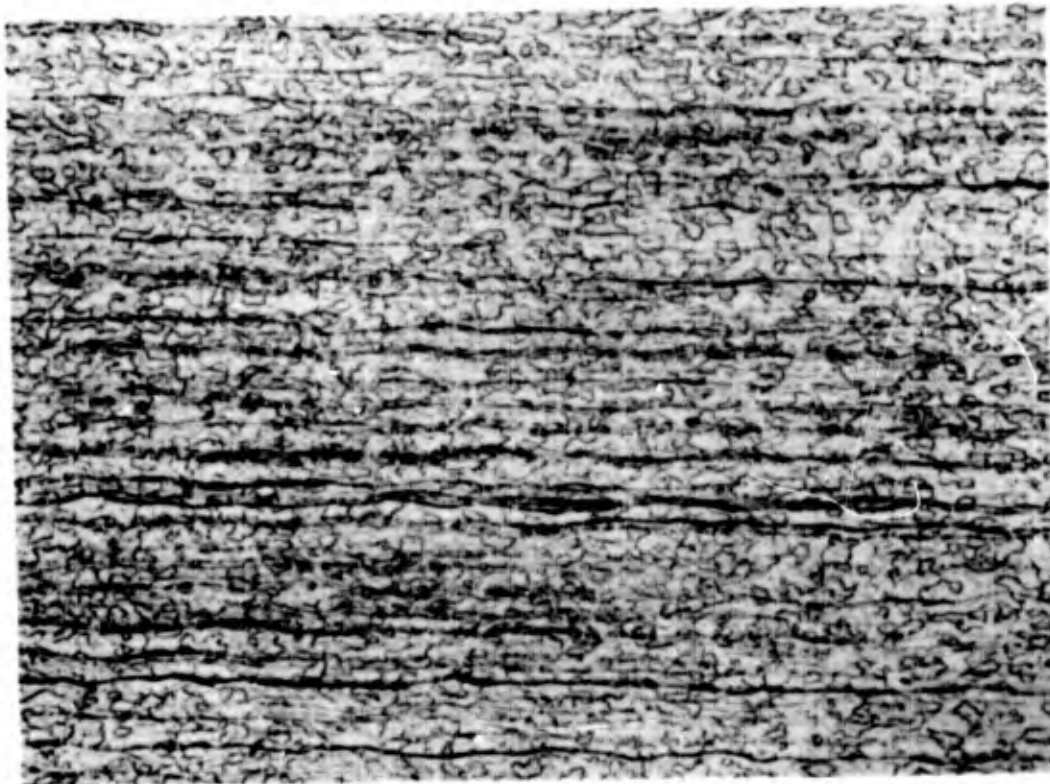


Figure 5  
Neg. No. 13733

Magnification: 100X

Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 5: Microstructure of longitudinal section of recrystallized 0.060-inch Cb-752 sheet annealed one hour at 2300°F, Heat 52208.

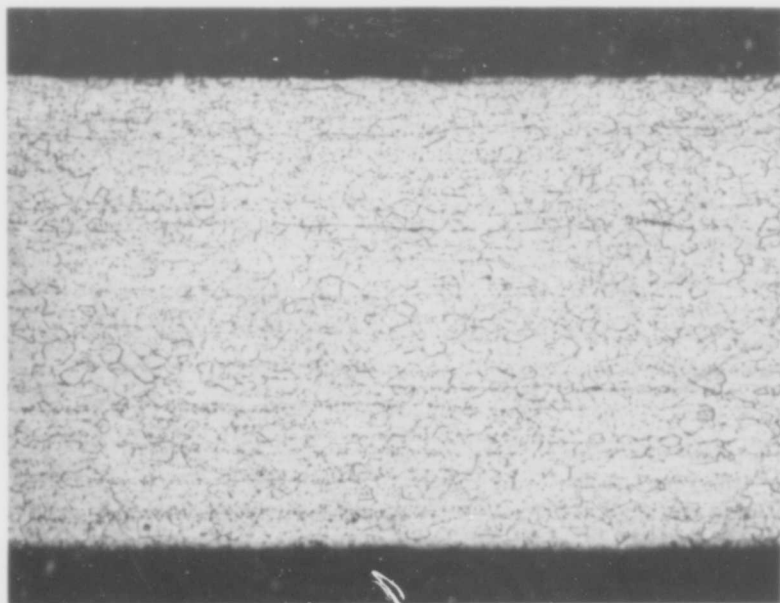


Figure 6  
Neg. No. 14310

Magnification: 200X

Etchant: HF, HNO<sub>3</sub> + H<sub>2</sub>O

Figure 6: Microstructure of Cb-752 sheet vacuum annealed one hour at 2300°F prior to shipment to Douglas Aircraft Corporation, Heat 52165.

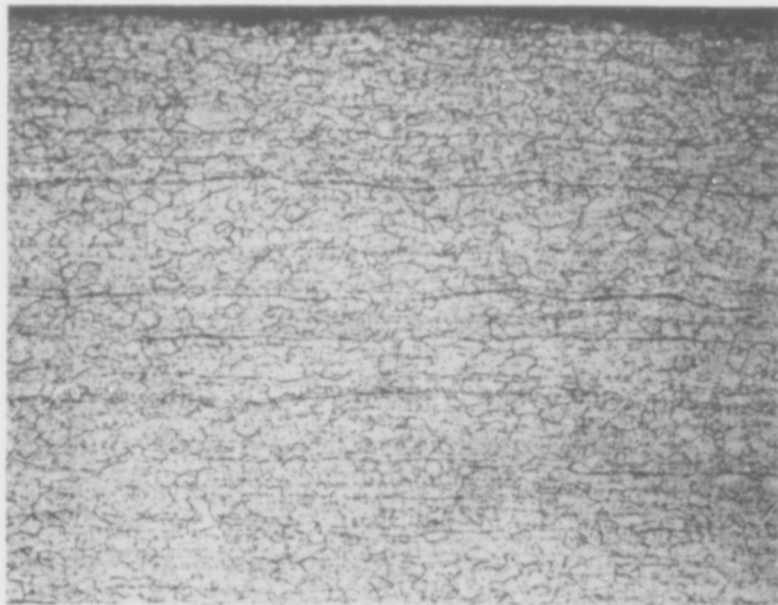


Figure 7  
Neg. No. 14311

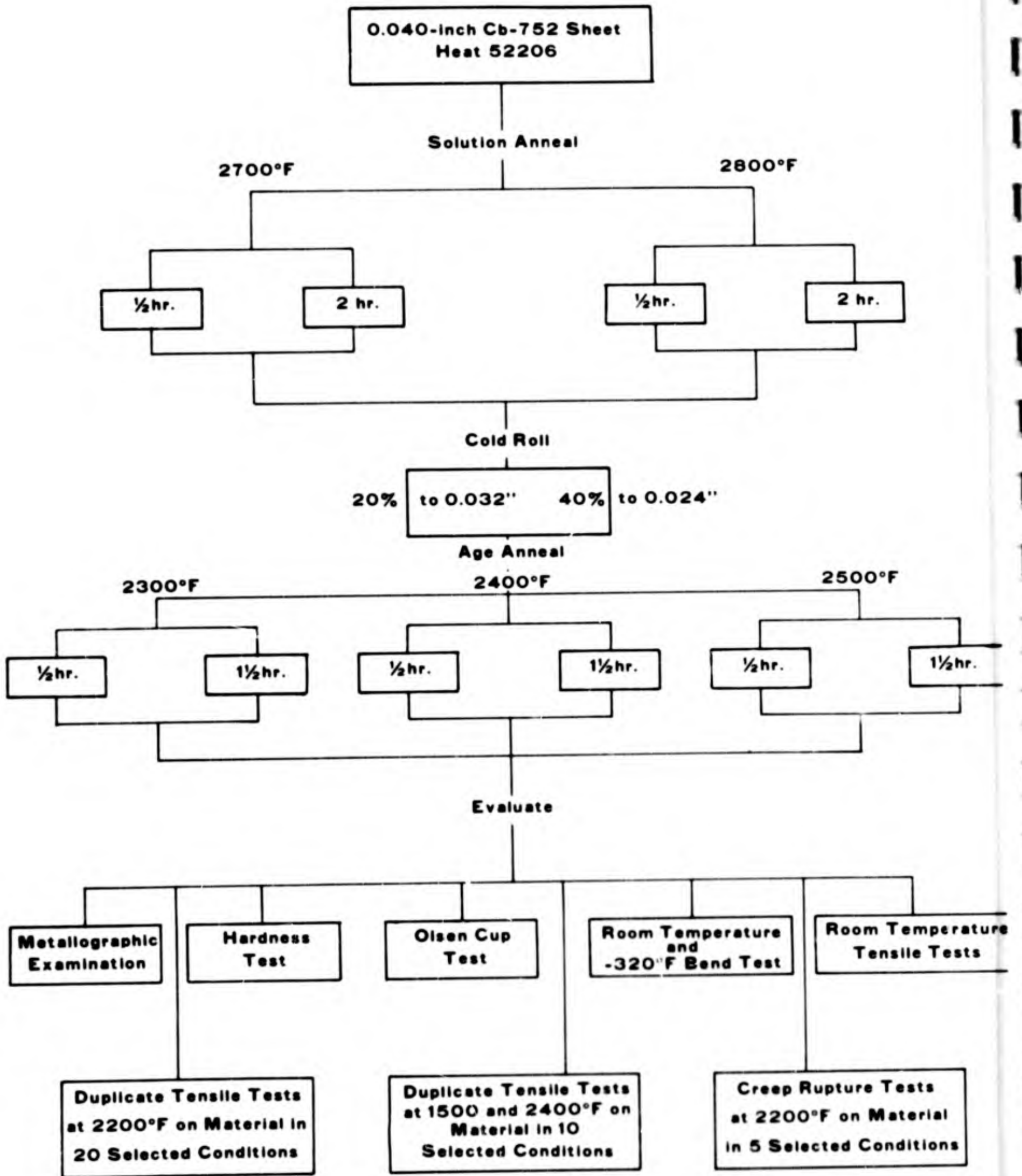
Magnification: 200X

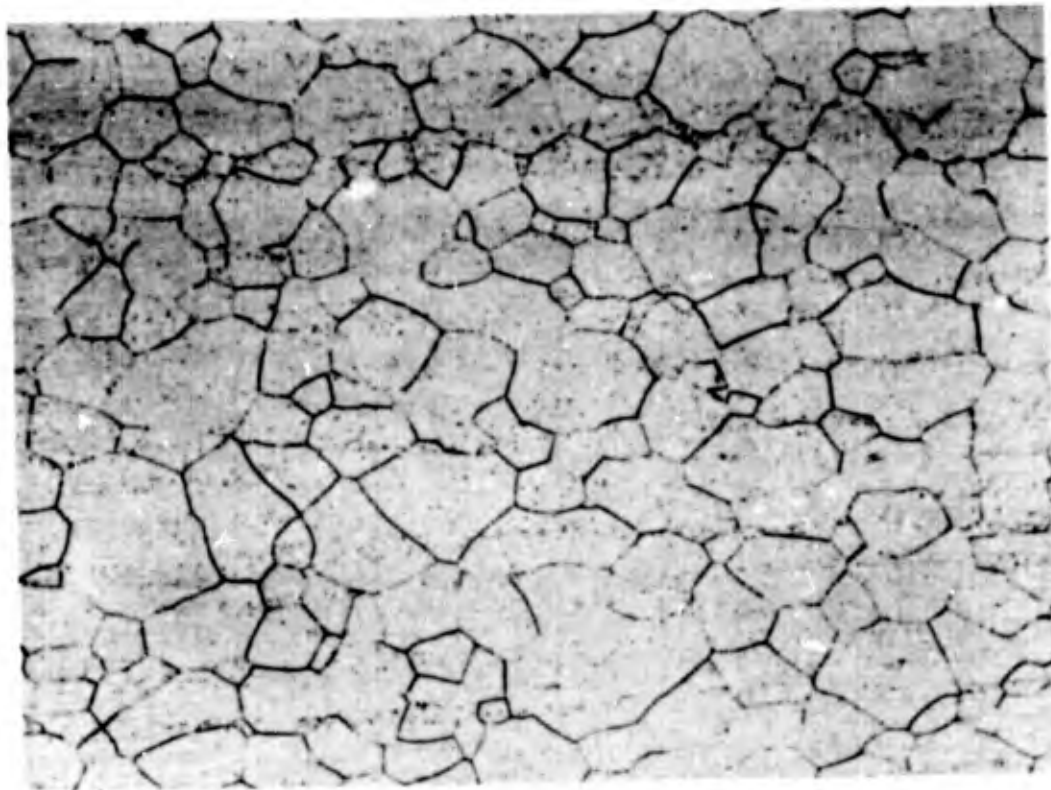
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 7: Microstructure of Cb-752 sheet vacuum annealed one hour at 2300°F prior to shipment to Martin Company, Heat 52227.

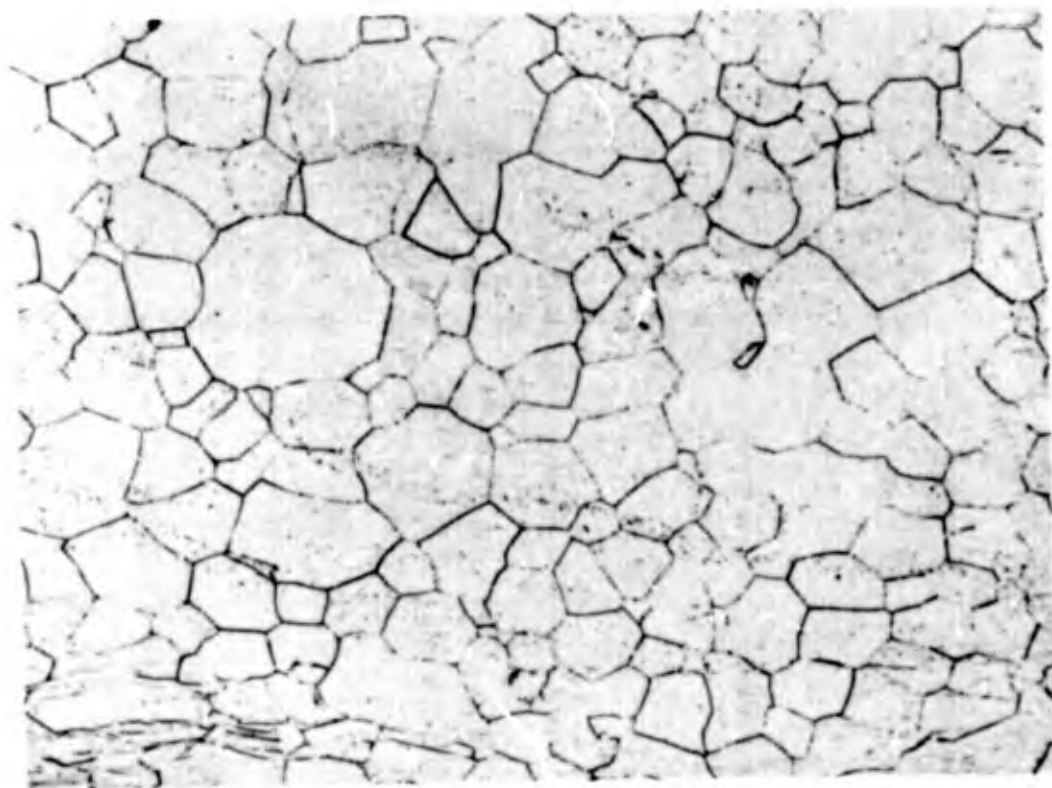
Figure 8

**SCHEMATIC DIAGRAM OF DUPLEX ANNEALING INVESTIGATION**





a) Neg. No. 13767



b) Neg. No. 13768

Magnification: 200X

Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 9: Microstructures of 0.040-inch Cb-752 sheet annealed for one-half hour at a) 2700°F and b) 2800°F, Heat 52206.

# Sampling Positions of Mechanical Test Samples

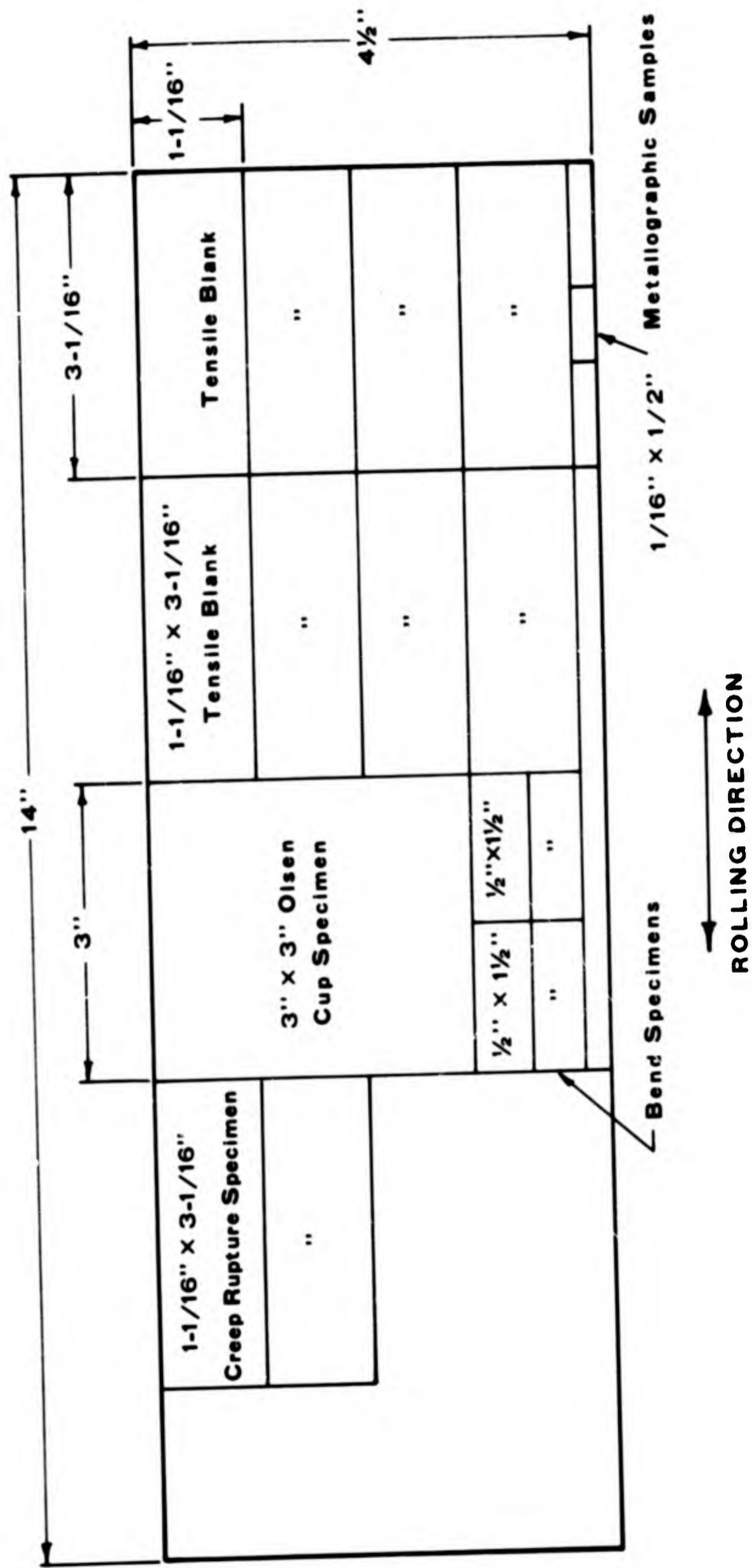
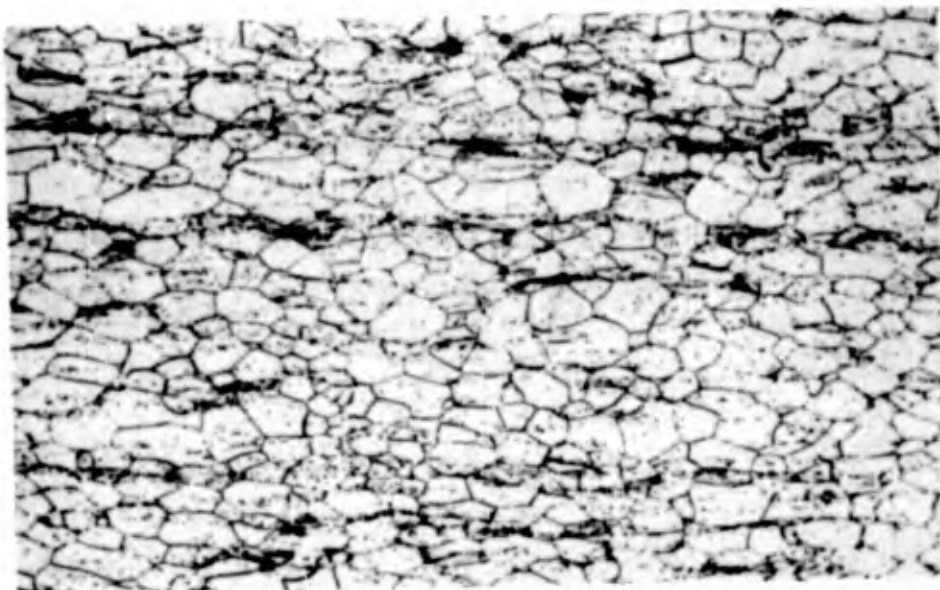


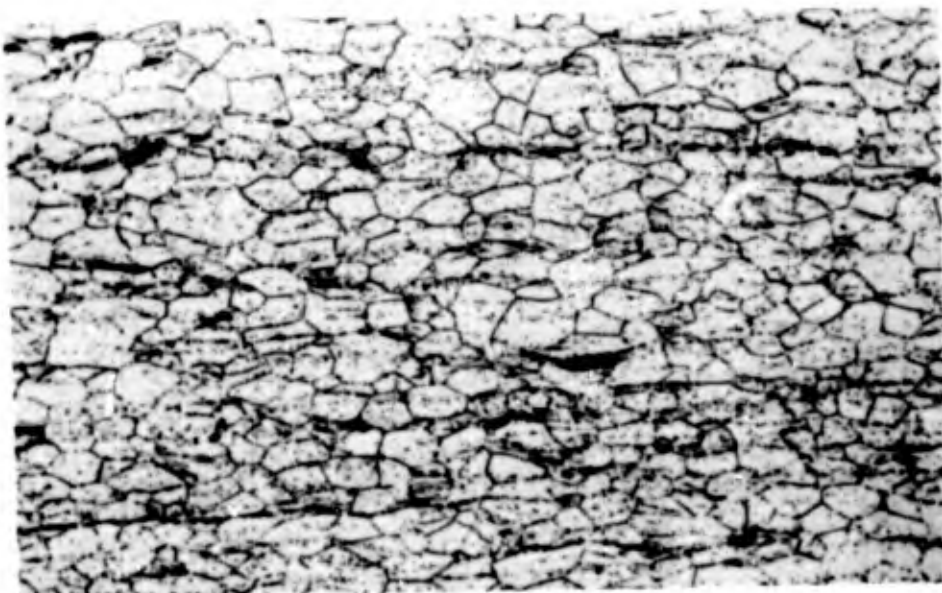
Figure 10

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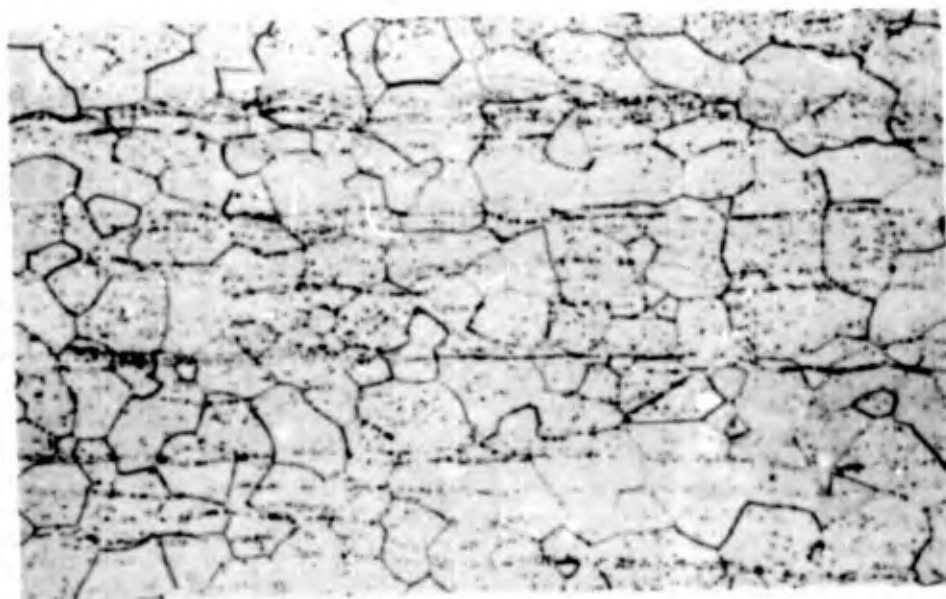
a) 2100°F  
Neg. No. 14378



b) 2300°F  
Neg. No. 14394



c) 2600°F  
Neg. No. 14435

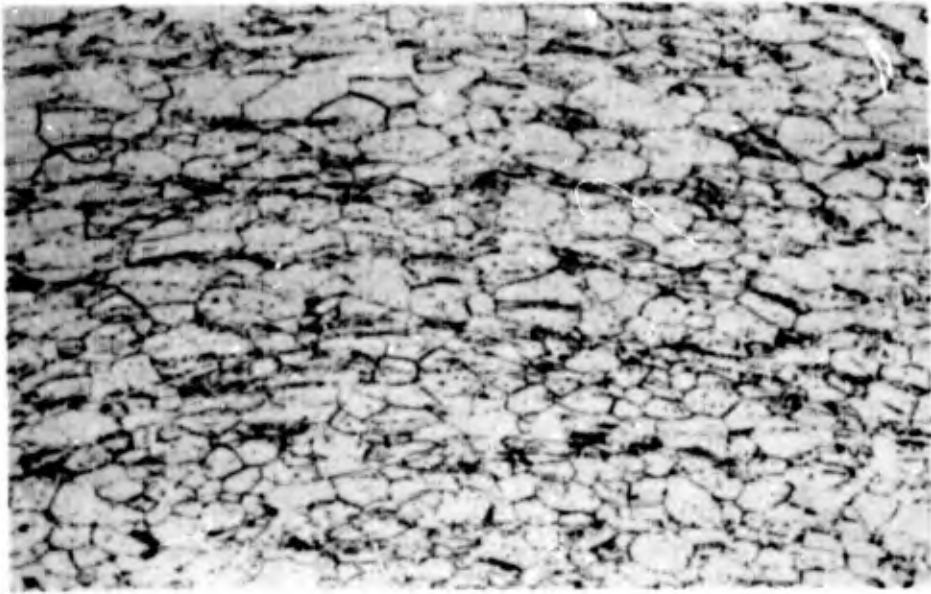


Magnification: 200X

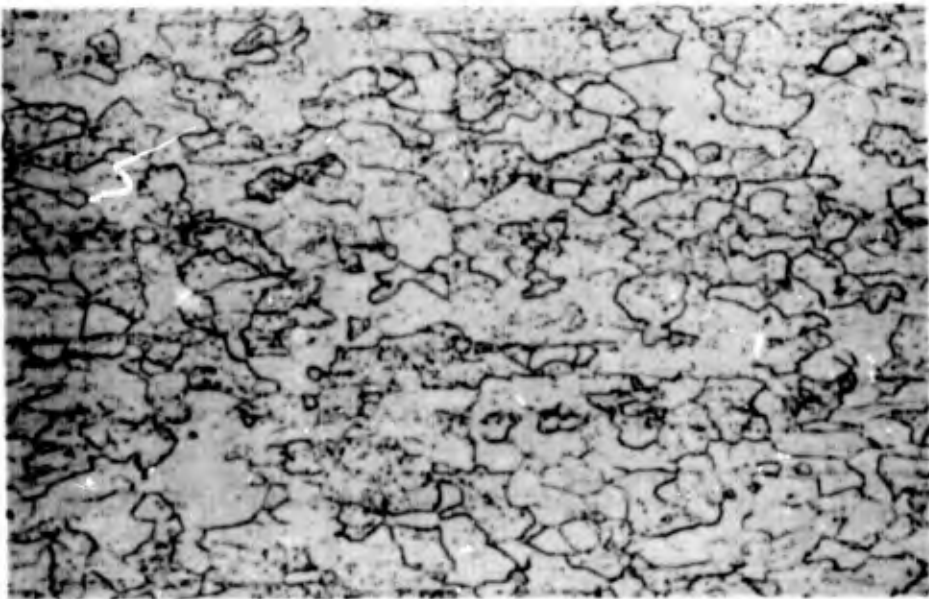
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 11: Microstructures of Cb-752 sheet solution annealed for one-half hour at 2700°F, cold reduced 20 percent to 0.032-inch and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

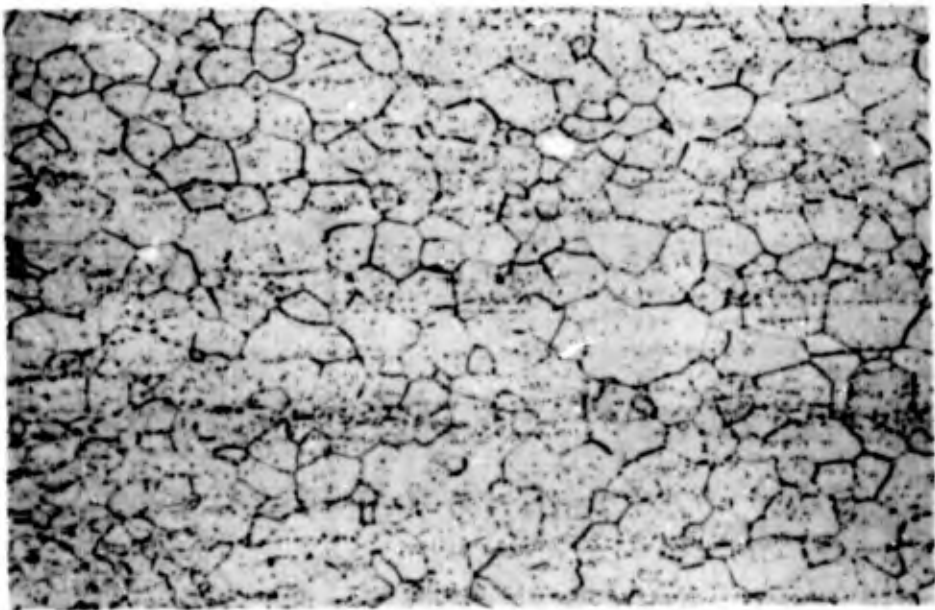
a) 2100°F  
Neg. No. 14382



b) 2300°F  
Neg. No. 14398



c) 2600°F  
Neg. No. 14439



Magnification: 200X

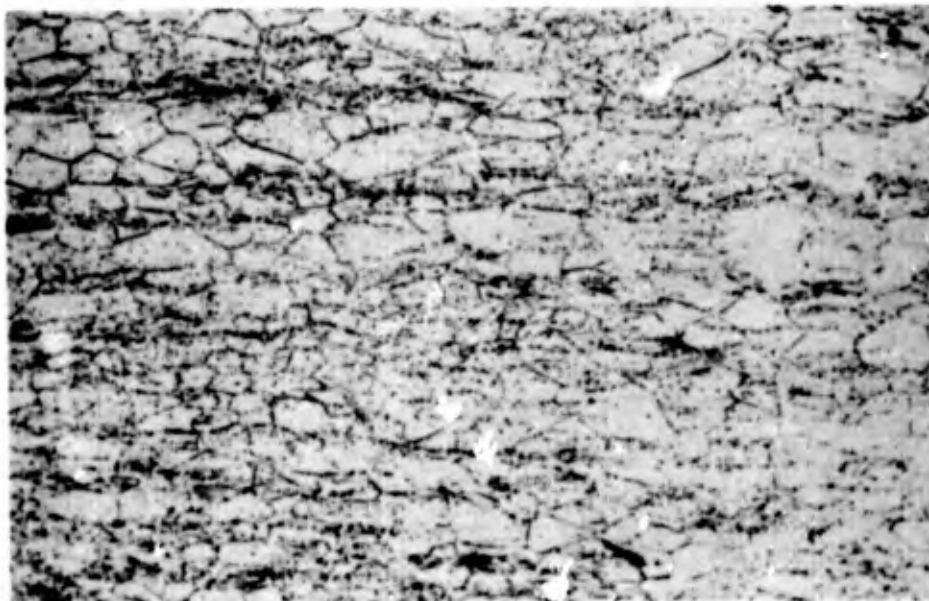
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 12: Microstructures of Cb-752 sheet solution annealed for one-half hour at 2700°F, cold reduced 40 percent to 0.024-inch and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

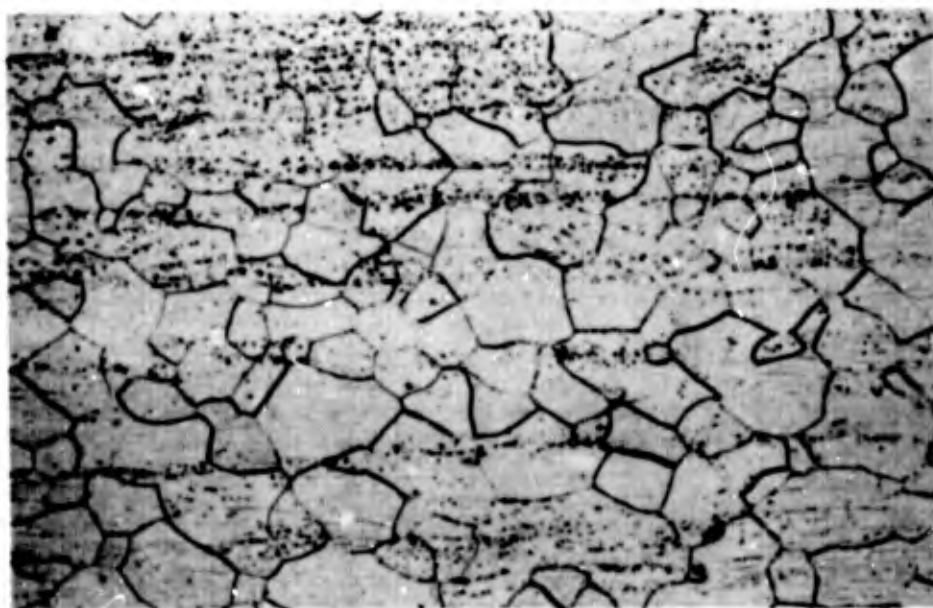
a) 2100°F  
Neg. No. 14397



b) 2300°F  
Neg. No. 14395



c) 2600°F  
Neg. No. 14436

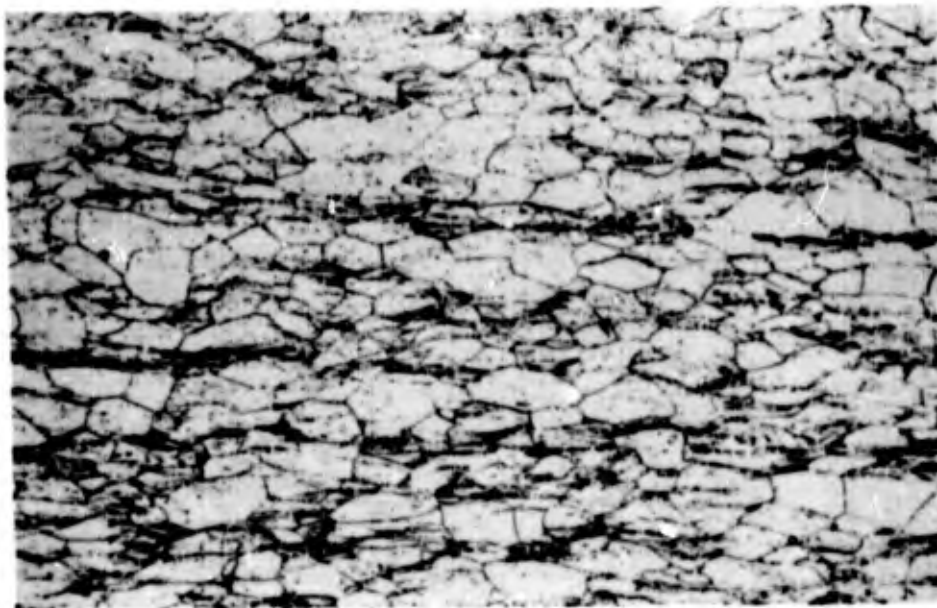


Magnification: 200X

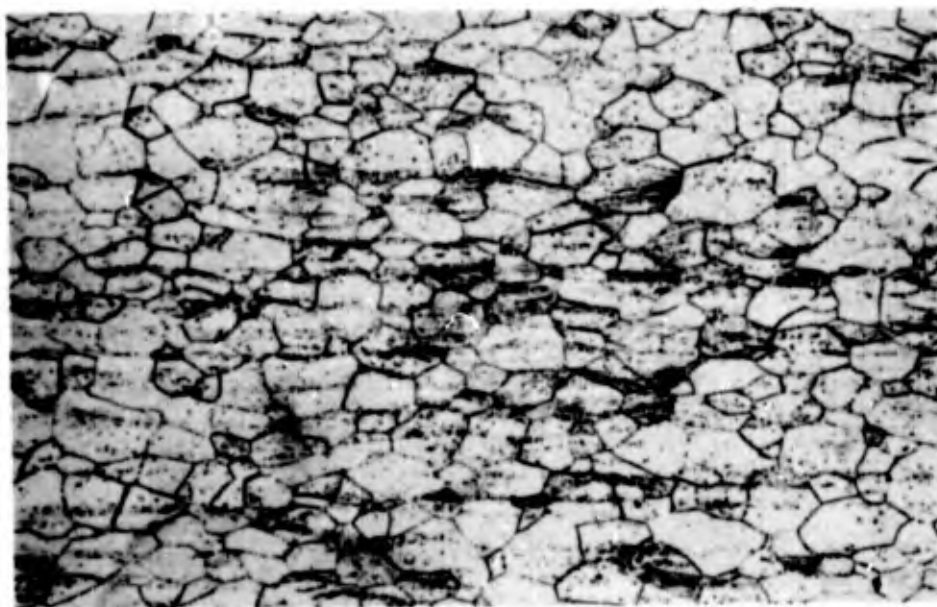
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 13: Microstructures of Cb-752 sheet solution annealed for two hours at 2700°F, cold reduced 20 percent to 0.032-inch and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

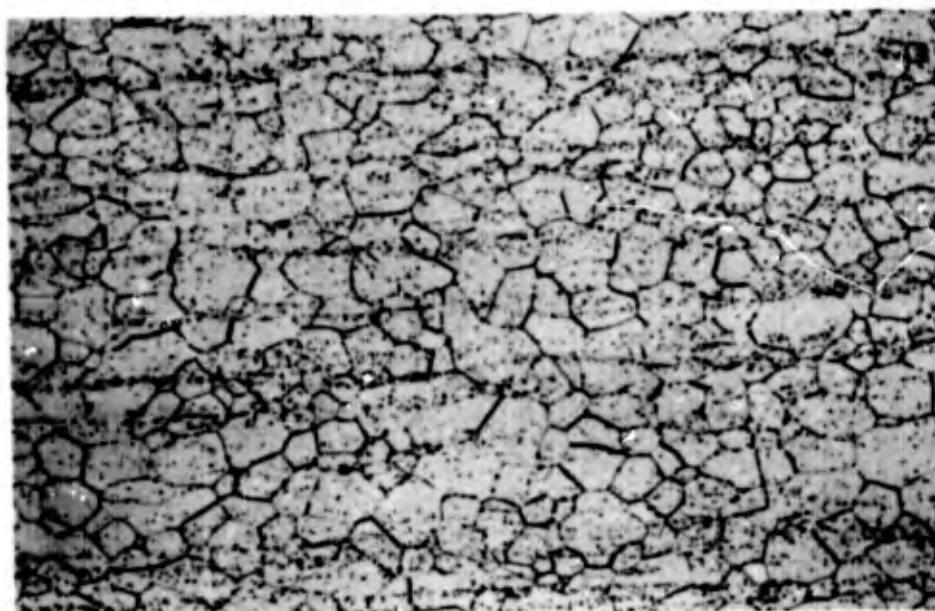
a) 2100°F  
Neg. No. 14383



b) 2300°F  
Neg. No. 14416



c) 2600°F  
Neg. No. 14440

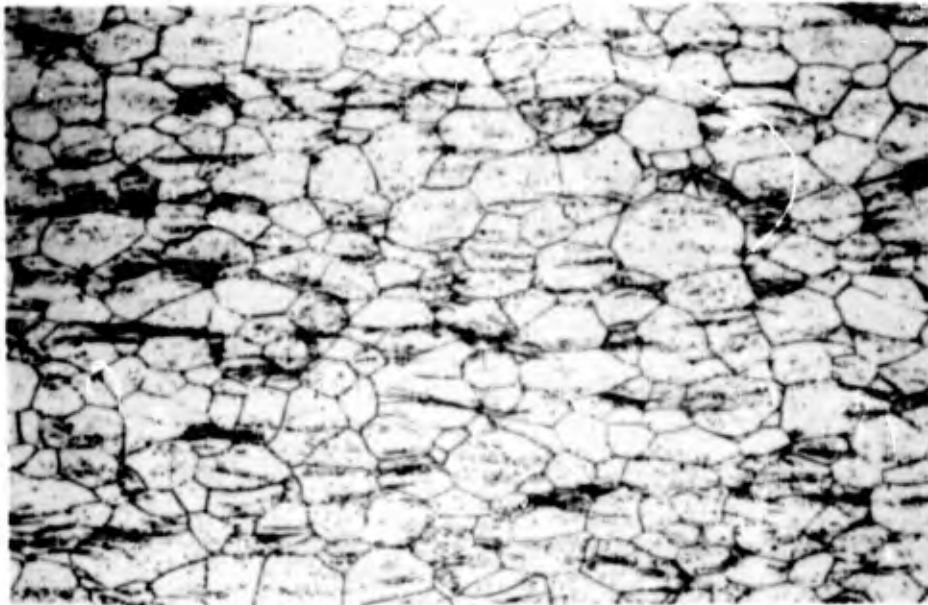


Magnification: 200X

Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 14: Microstructures of Cb-752 sheet solution annealed for two hours at 2700°F, cold reduced 40 percent to 0.024-inch and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

a) 2100°F  
Neg. No. 14380



b) 2300°F  
Neg. No. 14396



c) 2600°F  
Neg. No. 14437

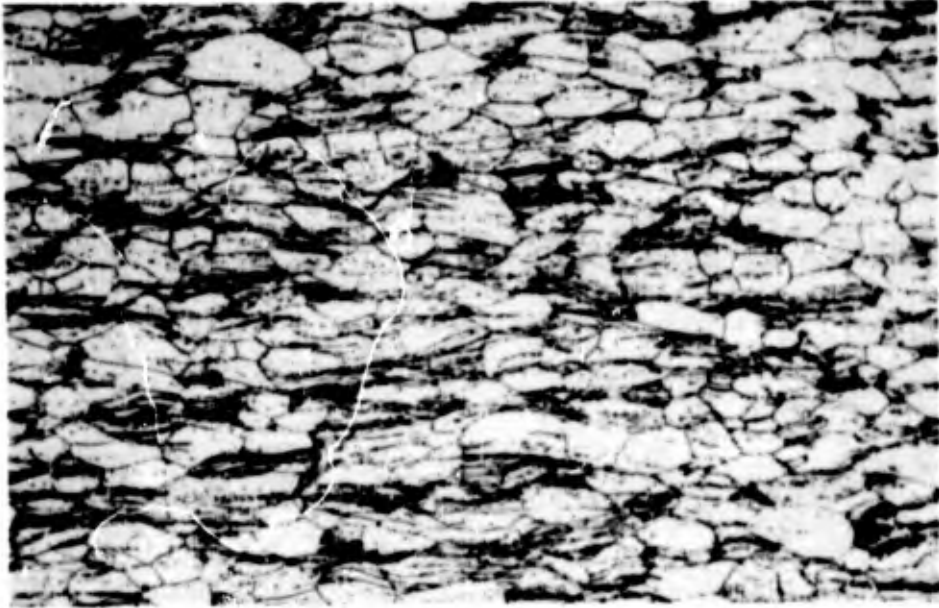


Magnification: 200X

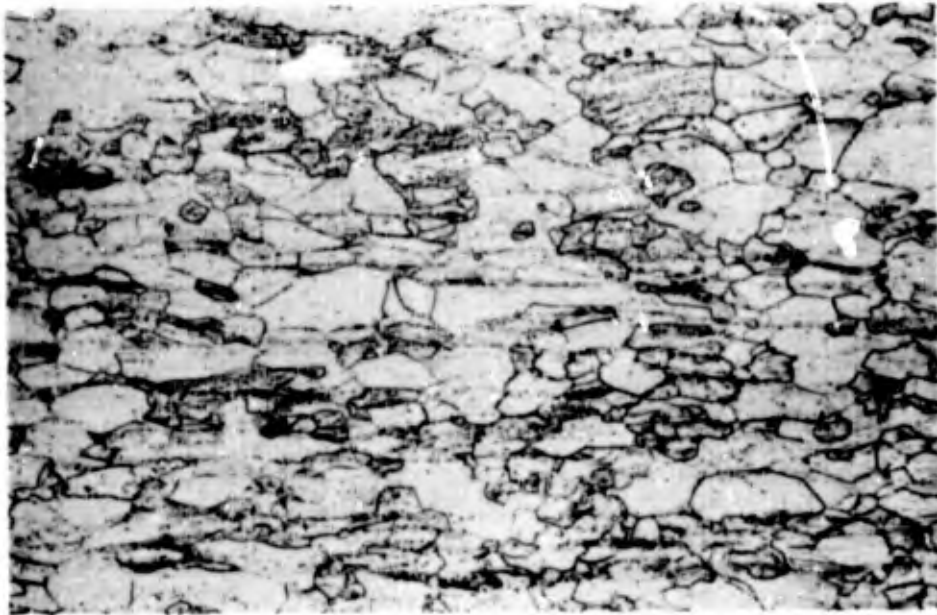
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 15: Microstructures of Cb-752 sheet solution annealed for one-half hour at 2800°F, cold reduced 20 percent to 0.032-inch, and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

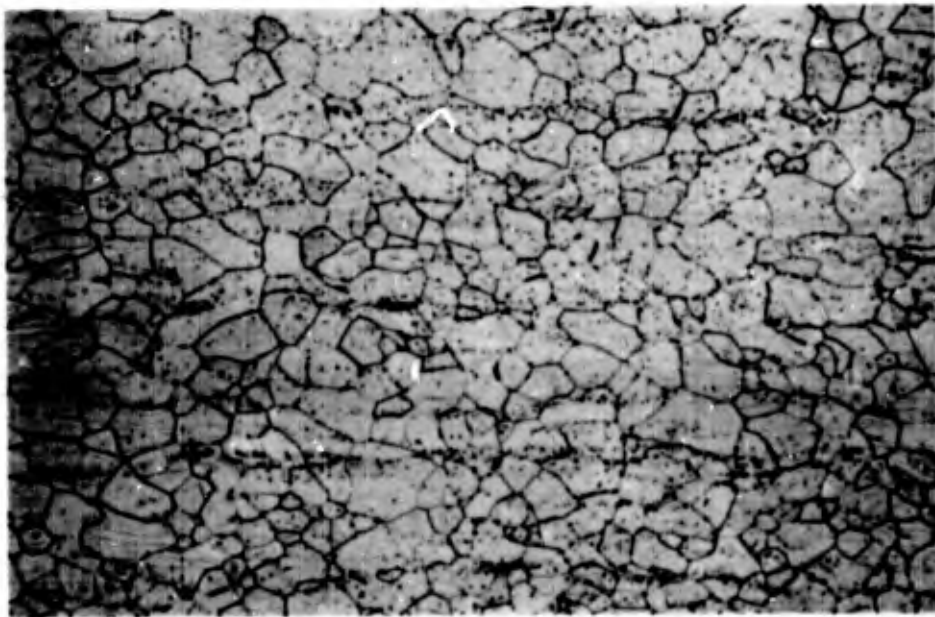
a) 2100°F  
Neg. No. 14384



b) 2300°F  
Neg. No. 14417



c) 2600°F  
Neg. No. 14441

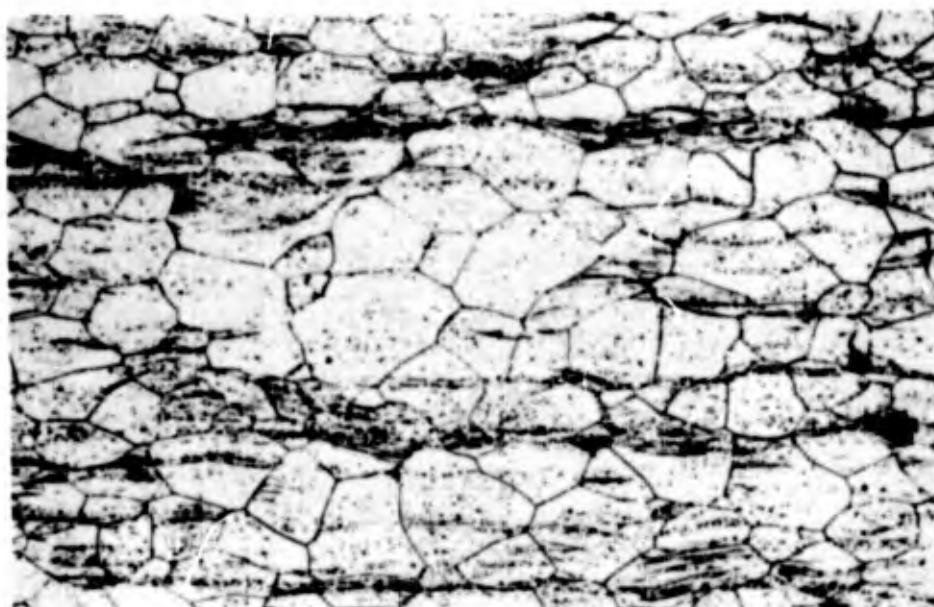


Magnification: 200X

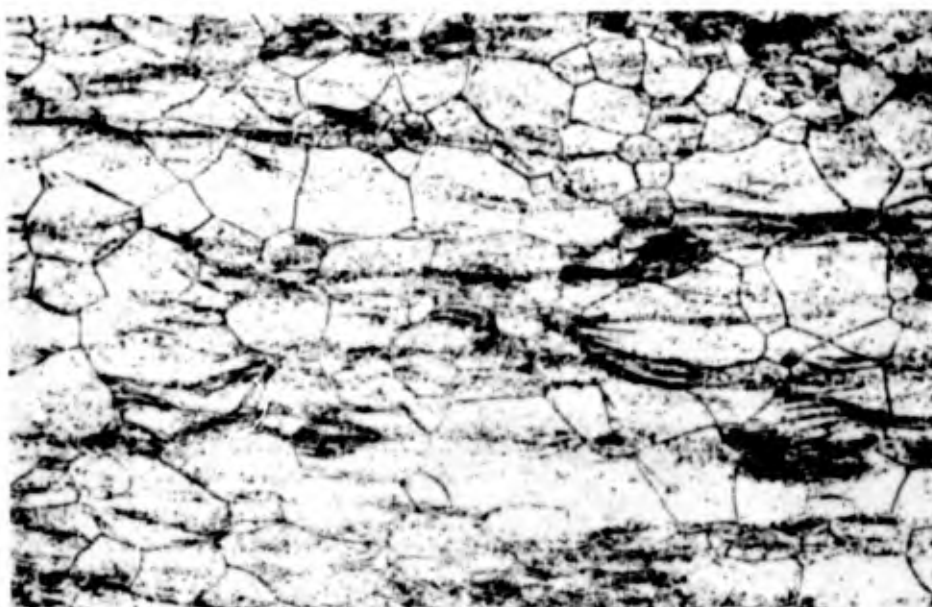
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 16: Microstructures of Cb-752 sheet solution annealed for one-half hour at 2800°F, cold reduced 40 percent to 0.024-inch, and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

a) 2100°F  
Neg. No. 14381



b) 2300°F  
Neg. No. 14297



c) 2600°F  
Neg. No. 14438

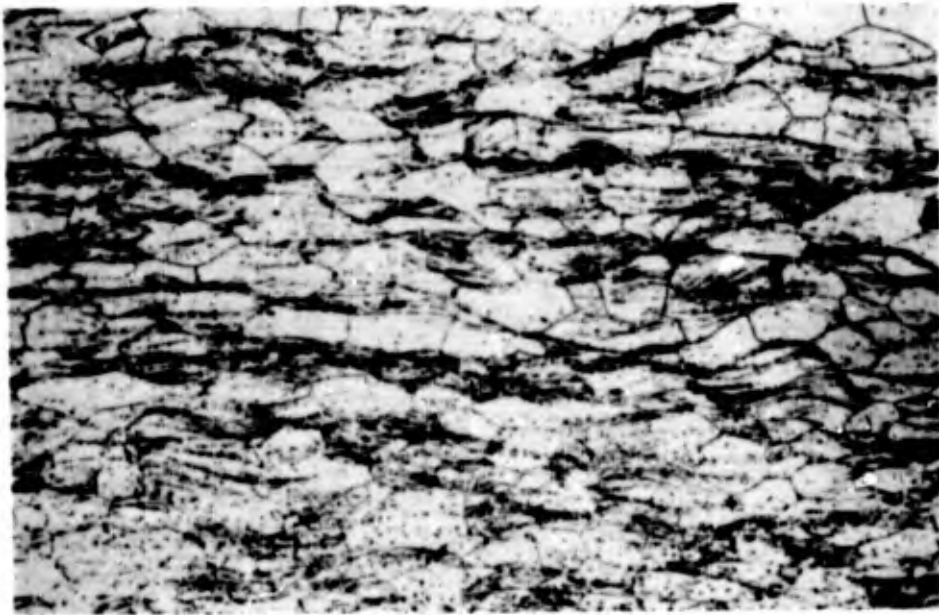


Magnification: 200X

Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 17: Microstructures of Cb-752 sheet solution annealed for two hours at 2800°F, cold reduced 20 percent to 0.032-inch, and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

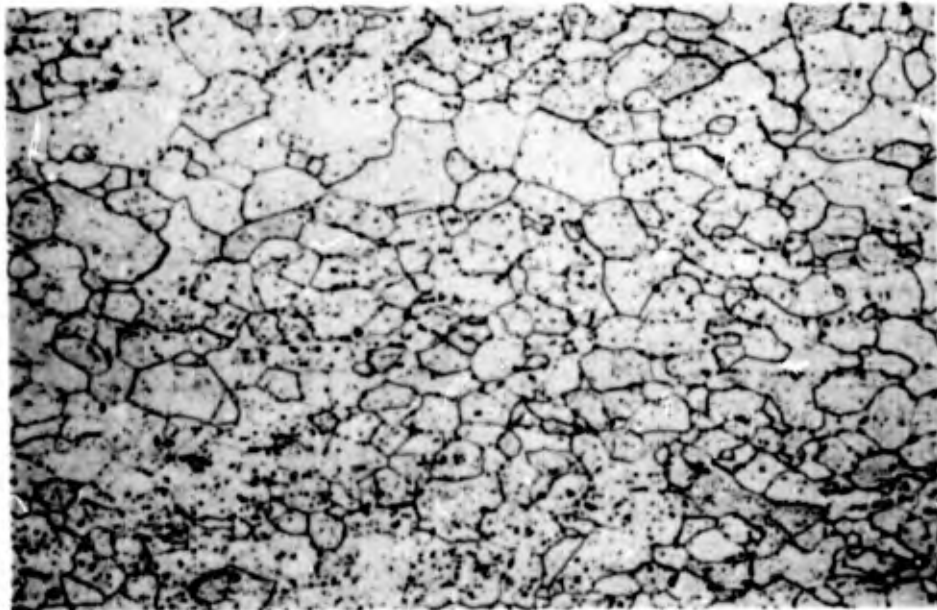
a) 2100°F  
Neg. No. 14385



b) 2300°F  
Neg. No. 14418



c) 2600°F  
Neg. No. 14442

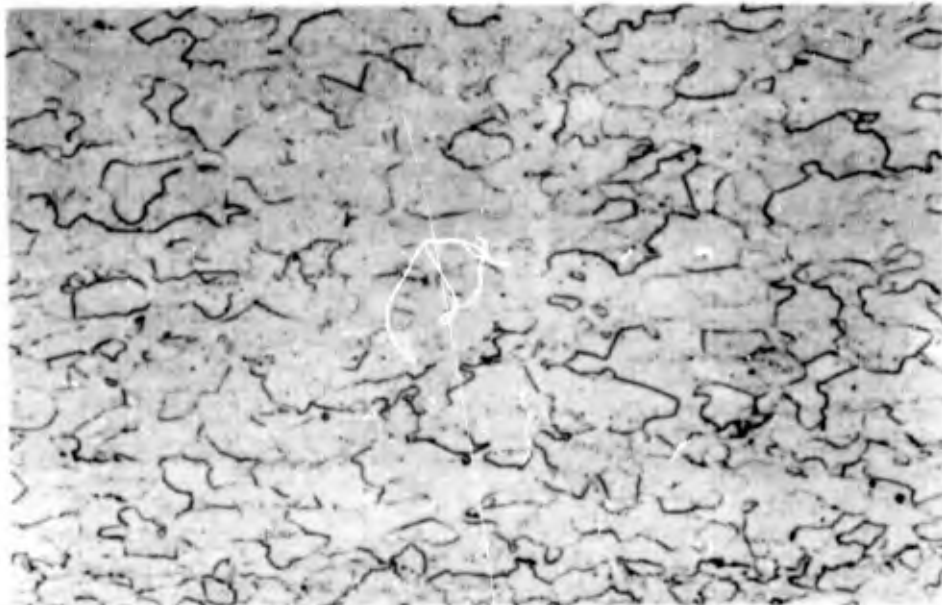


Magnification: 200X

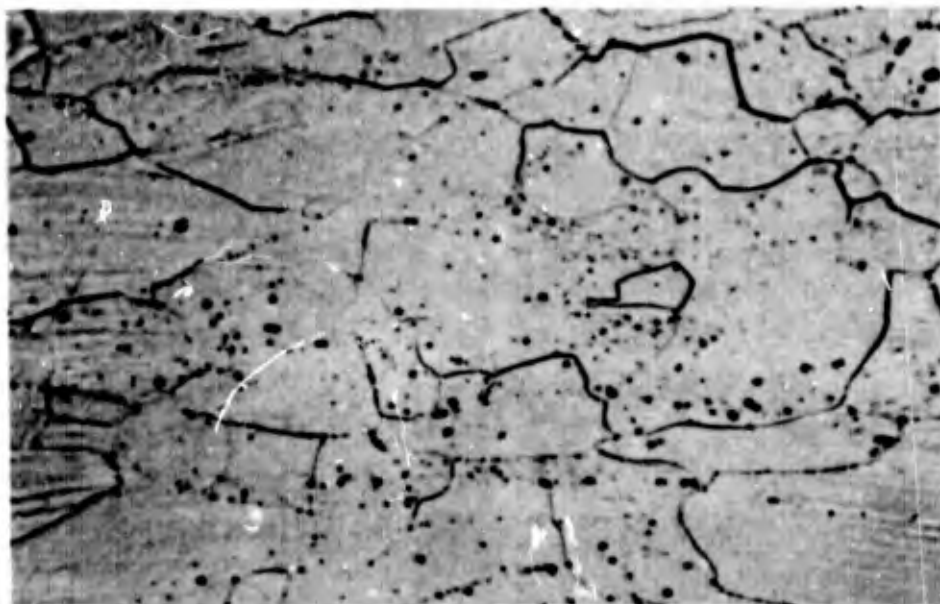
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O

Figure 18: Microstructures of Cb-752 sheet solution annealed for two hours at 2800°F, cold reduced 40 percent to 0.024-inch, and given final anneals for one hour at 2100, 2300, and 2600°F, Heat 52206.

a) Neg. No. 14375  
Magnification: 200X



b) Neg. No. 14376  
Magnification: 1000X



Sheet No. 2A<sub>2</sub>

Heat Treatment: 2700°F (2 hours) + 40 percent reduction + 2300°F (1/2 hour)

-320°F Bend Radius: 0.060-inch

Olsen Cup Failure: 0.3205-inch, ductile

Ultimate Tensile Strength, Room Temperature: 89,400 psi

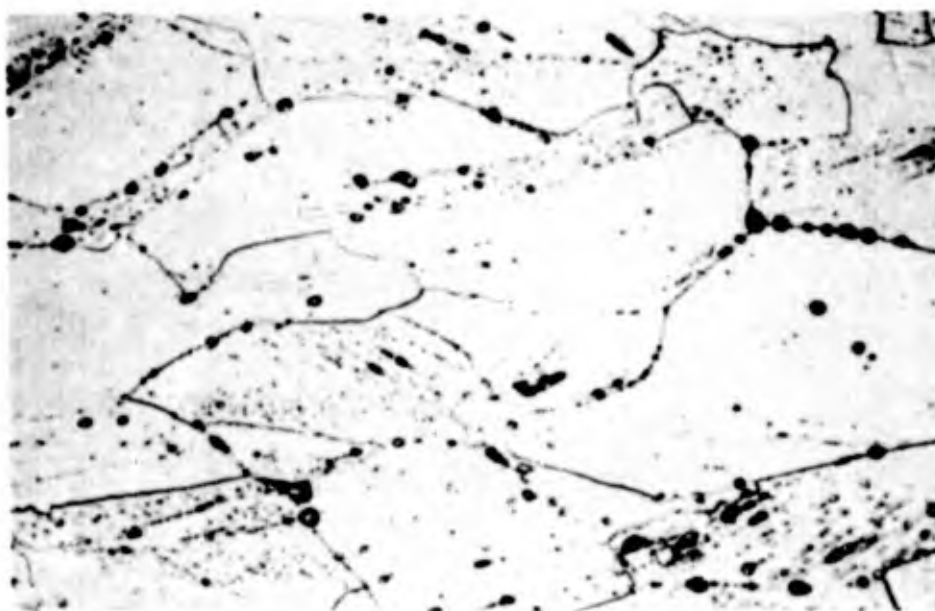
Ultimate Tensile Strength, 2200°F: Not determined

Figure 19: Microstructure of duplex annealed Cb-752 sheet 2A<sub>2</sub>, Heat 52206.  
Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O.

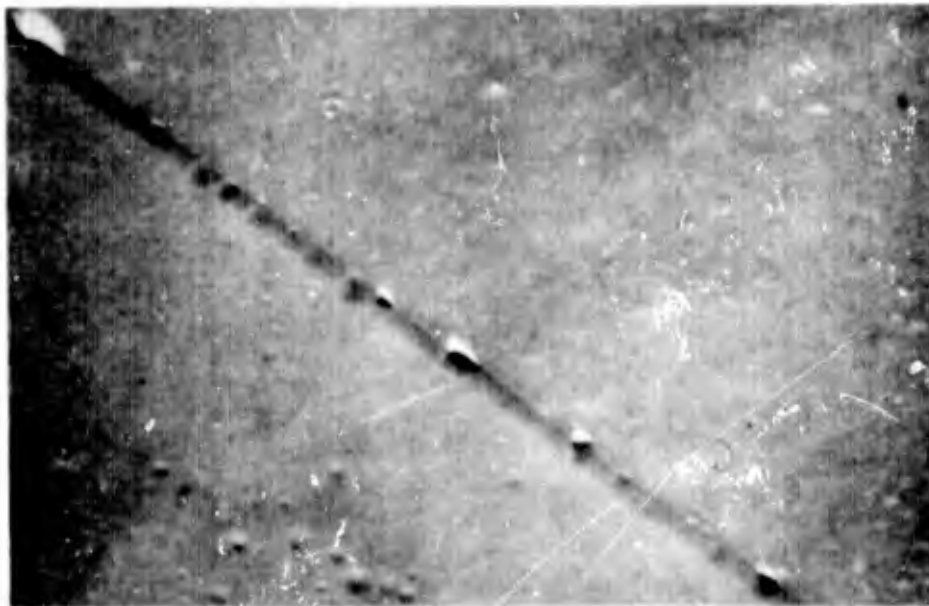
a) Neg. No. 14377  
Magnification: 200X



b) Neg. No. 14495  
Magnification: 1000X



c) Neg. No. 104  
Electron micrograph  
Magnification: 9000X



Sheet No. 3A<sub>2</sub>

Heat Treatment: 2800°F (1/2 hour) + 40 percent reduction + 2300°F (1/2 hour)

-320°F Bend Radius: 0.060-inch

Olsen Cup Failure: 0.2975-inch, ductile

Ultimate Tensile Strength, Room Temperature: 92,700 psi

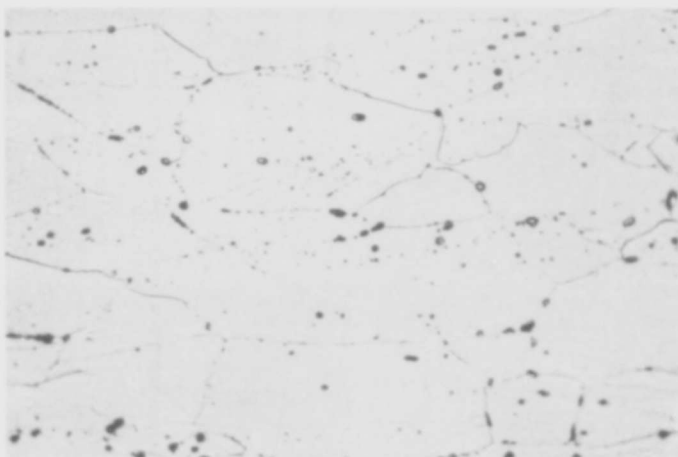
Ultimate Tensile Strength, 2200°F: 36,900 psi

Figure 20: Microstructure of duplex annealed Cb-752 sheet 3A<sub>2</sub>, Heat 52206.  
Etchant: a) and b) HF + HNO<sub>3</sub> + H<sub>2</sub>O.

a) Neg. No. 14460  
Magnification: 200X



b) Neg. No. 14461  
Magnification: 1000X



c) Neg. No. 96  
Electron micrograph  
Magnification: 9000X



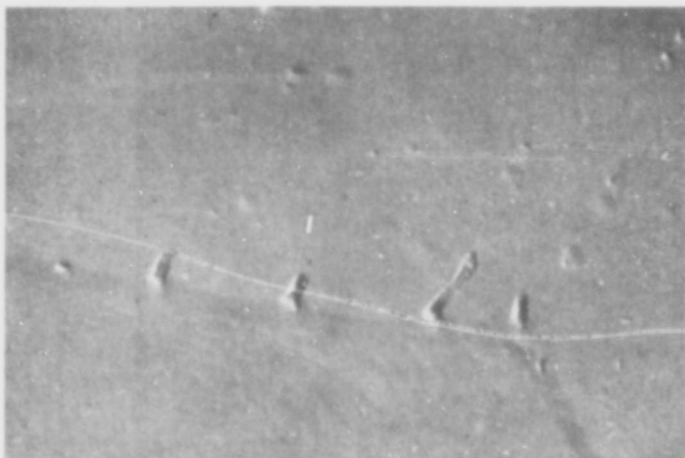
Sheet No. 2B<sub>1</sub>  
Heat Treatment: 2700°F (2 hours) + 20 percent reduction + 2400°F (1/2 hour)  
-320°F Bend Radius: >0.060-inch  
Olsen Cup Failure: 0.4350-inch, ductile  
Ultimate Tensile Strength, Room Temperature: 87,700 psi  
Ultimate Tensile Strength, 2200°F: 35,100 psi

Figure 21: Microstructure of duplex annealed Cb-752 sheet 2B<sub>1</sub>, Heat 52206.  
Etchant: a) and b) HF + HNO<sub>3</sub> + H<sub>2</sub>O.

a) Neg. No. 14299  
Magnification: 200X



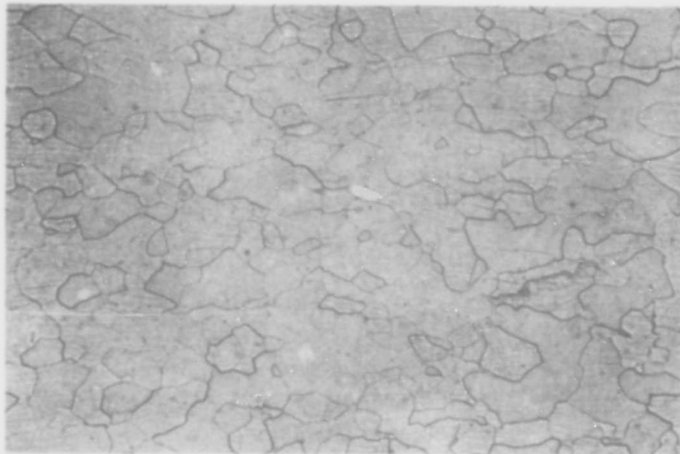
b) Neg. No. 100  
Electron micrograph  
Magnification: 9000X



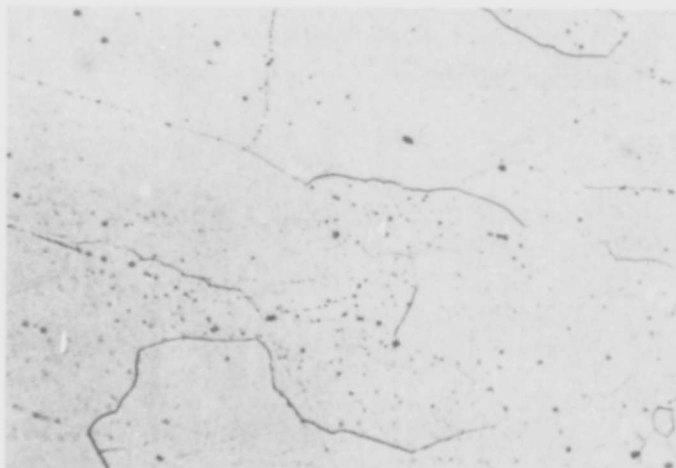
Sheet No. 3B<sub>1</sub>  
Heat Treatment: 2800°F (1/2 hour) + 20 percent reduction + 2400°F (1/2 hour)  
-320°F Bend Radius: > 0.120-inch  
Olsen Cup Failure: 0.4030-inch, ductile  
Ultimate Tensile Strength, Room Temperature: 88,200 psi  
Ultimate Tensile Strength, 2200°F: 34,500 psi

Figure 22: Microstructure of duplex annealed Cb-752 sheet 3B<sub>1</sub>, Heat 52206.  
Etchant: a) HF + HNO<sub>3</sub> + H<sub>2</sub>O .

a) Neg. No. 14302  
Magnification: 200X



b) Neg. No. 14303  
Magnification: 1000X



Sheet No. 3F<sub>2</sub>

Heat Treatment: 2800°F (1/2 hour) + 40 percent reduction + 2500°F (1-1/2 hours)

-320°F Bend Radius: > 0.120-inch

Olsen Cup Failure: 0.2850-inch, ductile

Ultimate Tensile Strength, Room Temperature: 82,300 psi

Ultimate Tensile Strength, 2200°F: Not determined

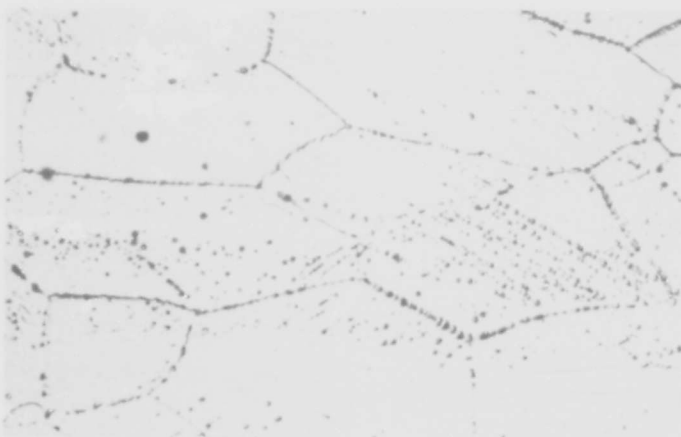
Figure 23: Microstructure of duplex annealed Cb-752 sheet 3F<sub>2</sub>, Heat 52206.

Etchant: HF + HNO<sub>3</sub> + H<sub>2</sub>O.

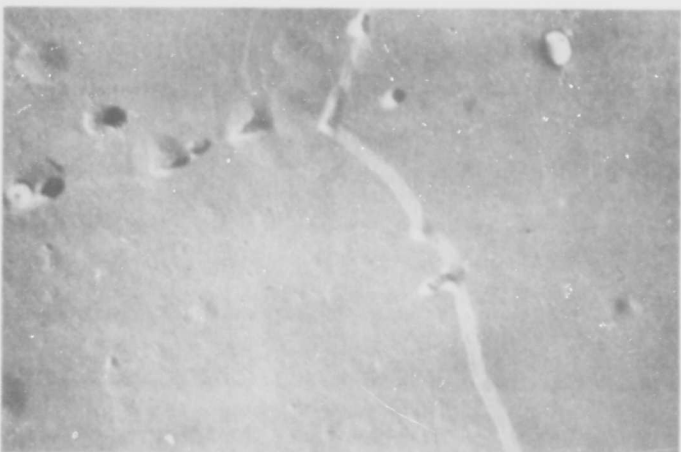
a) Neg. No. 14399  
Magnification: 200X



b) Neg. No. 14400  
Magnification: 1000X



c) Neg. No. 99  
Electron micrograph  
Magnification: 9000X



Sheet No. 4E<sub>1</sub>

Heat Treatment: 2800°F (2 hours) + 20 percent reduction + 2400°F (1-1/2 hours)

-320°F Bend Radius: >0.120-inch

Olsen Cup Failure: 0.3014-inch, brittle

Ultimate Tensile Strength, Room Temperature: 85,700 psi

Ultimate Tensile Strength, 2200°F: Not determined

Figure 24: Microstructure of duplex annealed Cb-752 sheet 4E<sub>1</sub>, Heat 52206.  
Etchant: a) and b) HF + HNO<sub>3</sub> + H<sub>2</sub>O.

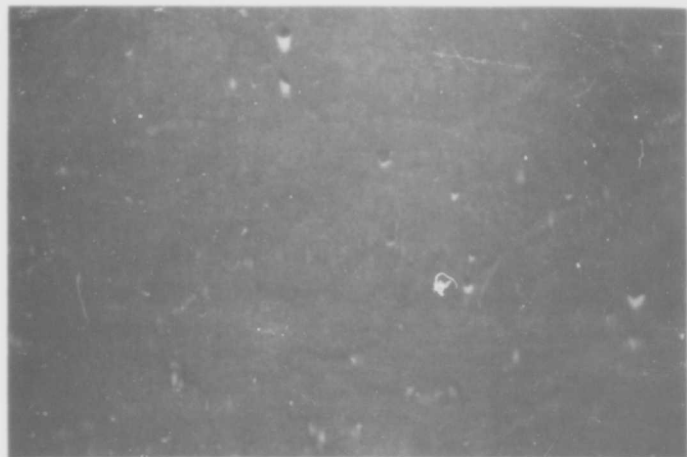
a) Neg. No. 14300  
Magnification: 200X



b) Neg. No. 14301  
Magnification: 1000X



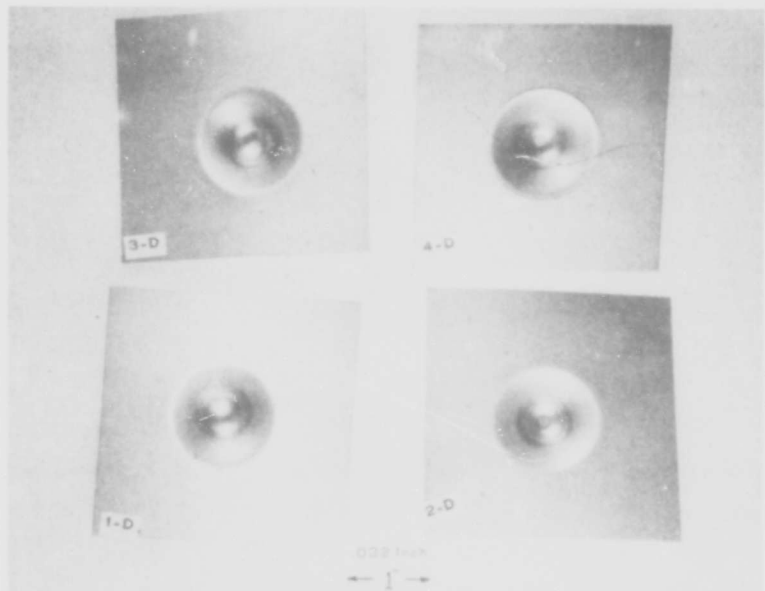
c) Neg. No. 102  
Magnification: 9000X



Sheet No. 4E<sub>2</sub>  
Heat Treatment: 2800°F (2 hours) + 40 percent reduction + 2400°F (1-1/2 hours)  
-320°F Bend Radius: 0.120-inch  
Olsen Cup Failure: 0.2700-inch, ductile  
Ultimate Tensile Strength, Room Temperature: 88,400 psi  
Ultimate Tensile Strength, 2200°F: 34,400 psi

Figure 25: Microstructure of duplex annealed Cb-752 sheet 4E<sub>2</sub>, Heat 52206.  
Etchant: a) and b) HF + HNO<sub>3</sub> + H<sub>2</sub>O.

Neg. No. 14136



Neg. No. 14134

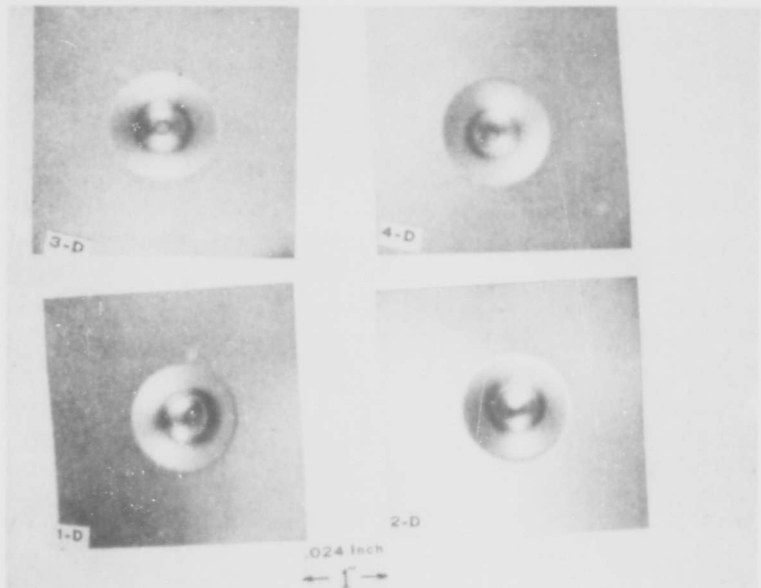
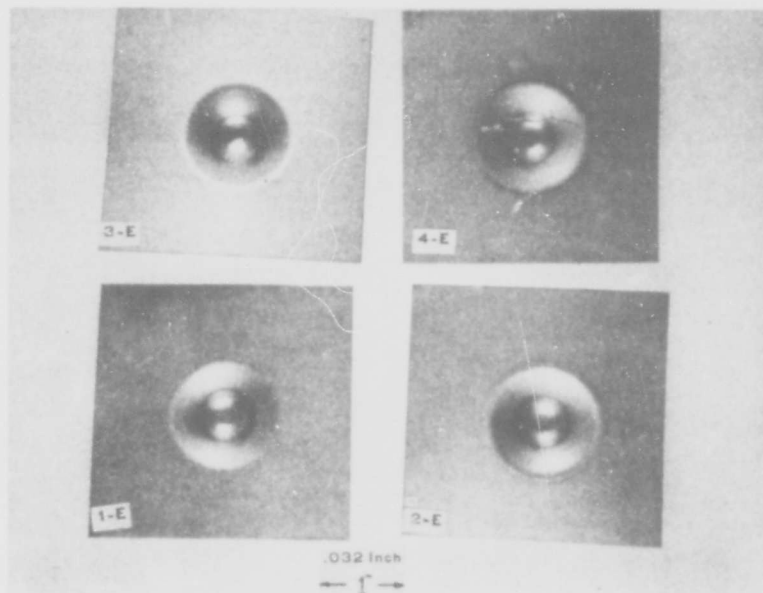


Figure 26: Olsen cup test specimens of duplex annealed 0.032 and 0.024-inch Cb-752 sheet (Note brittle failure of specimen 4D of the 0.032-inch thick sheet).

Neg. No. 14135



Neg. No. 14132

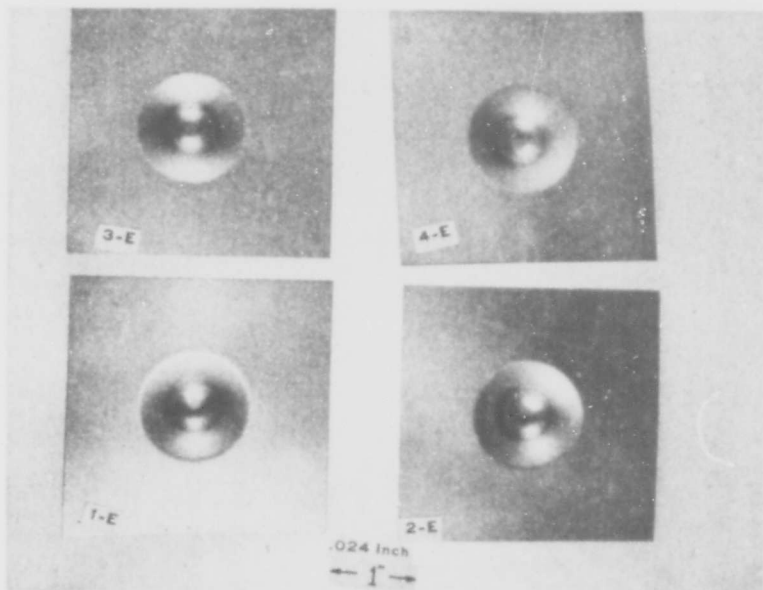


Figure 27: Olsen cup test specimens of duplex annealed 0.032 and 0.024-inch Cb-752 sheet (Note brittle failure of specimen 4E of the 0.032-inch thick sheet).

Figure 28

**Room Temperature Ultimate Tensile Strength of Cb-752  
Duplex Annealed Sheet Cold Reduced 20% to  
0.032-inch Prior to Indicated Final Aging Anneals**

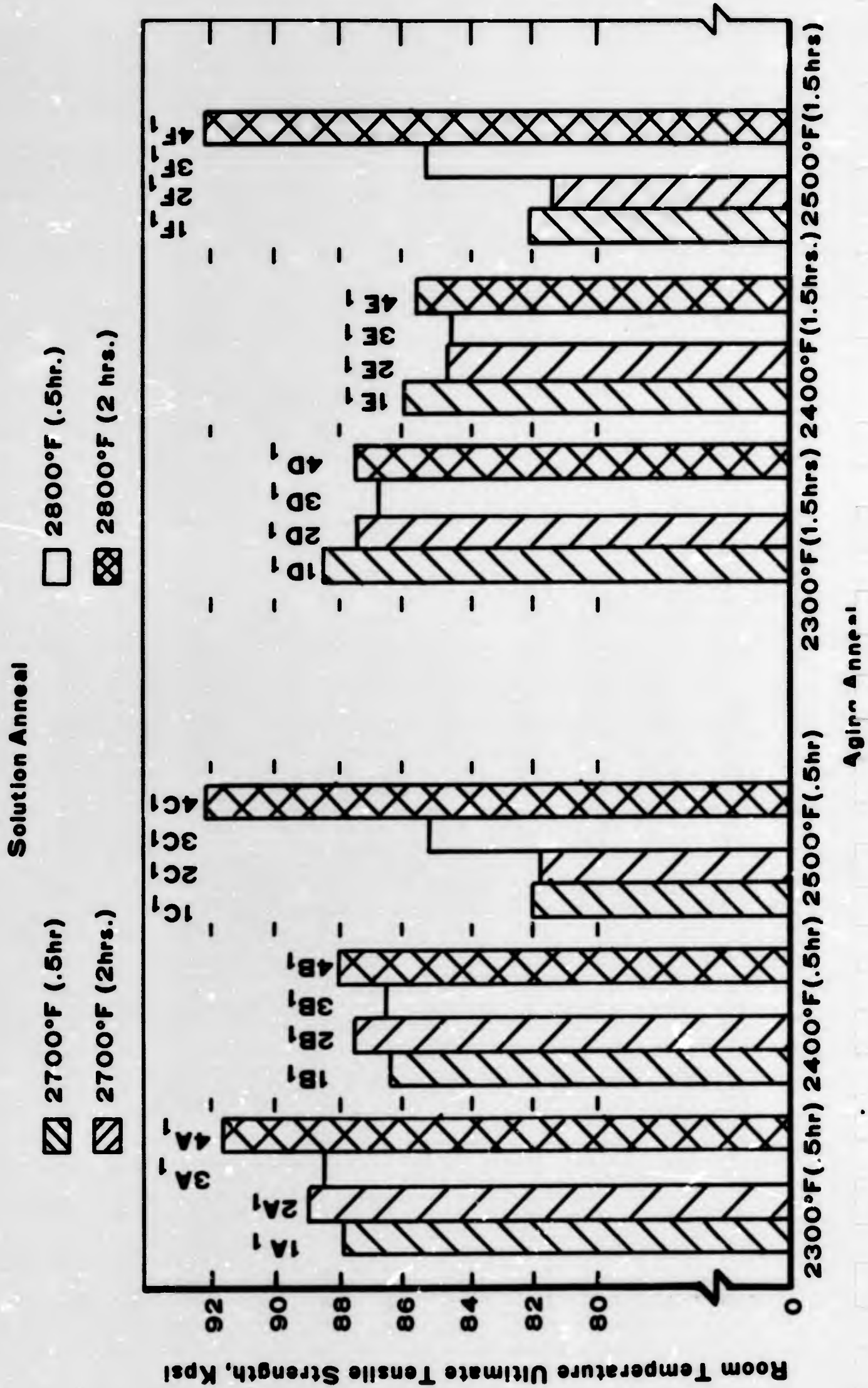


Figure 29

**Room Temperature Ultimate Tensile Strength of Cb-752 Duplex  
Annealed Sheet, Cold Reduced 40 Percent to  
0.024-inch Prior to Indicated Final Aging Anneals**

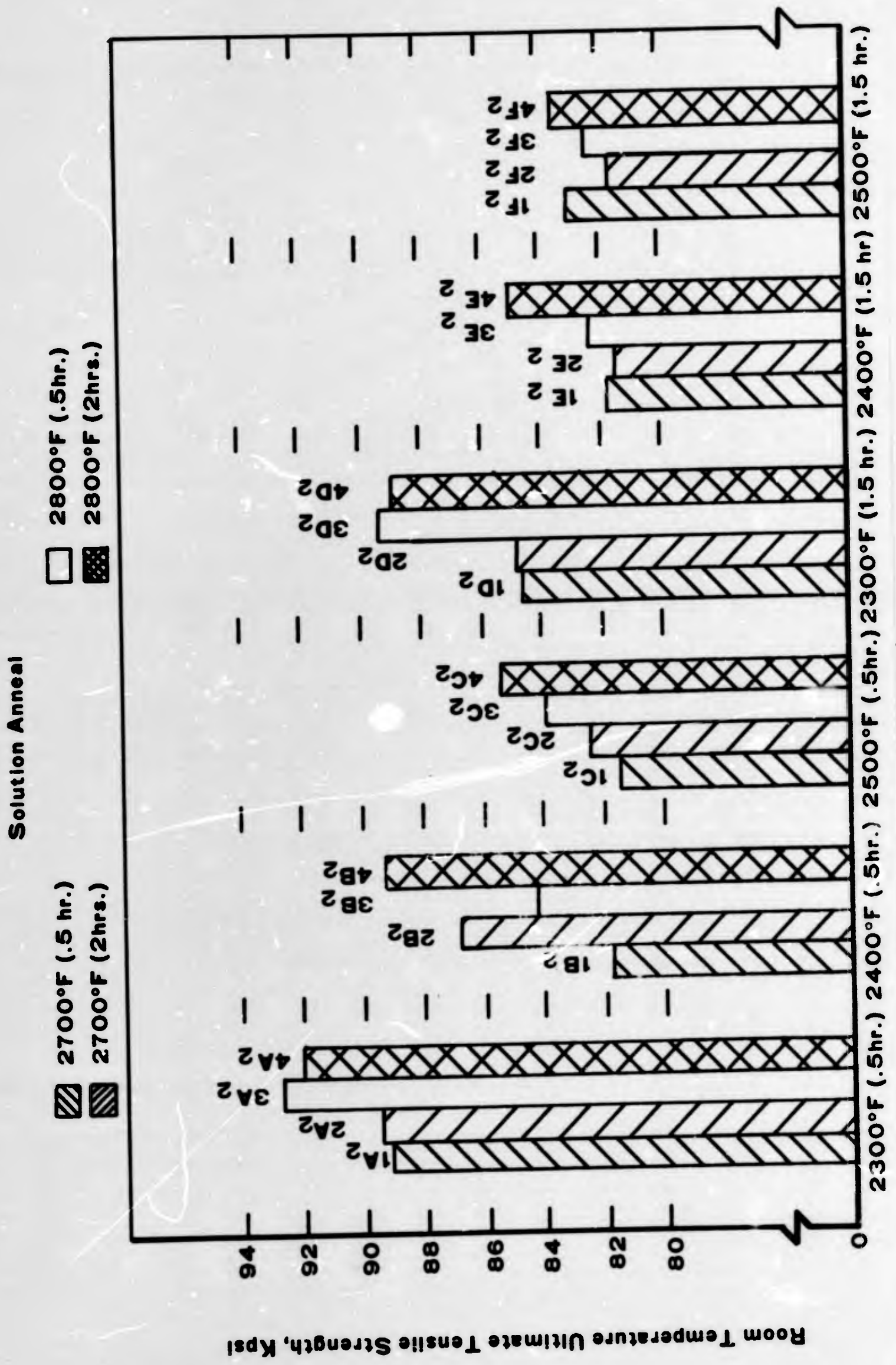


Figure 30

**Ultimate Tensile Strength of Cb-752 Duplex Annealed  
Sheet at 2200°F; Sheet Cold Reduced  
20 Percent to 0.032-inch Prior to Indicated Final Aging Anneals**

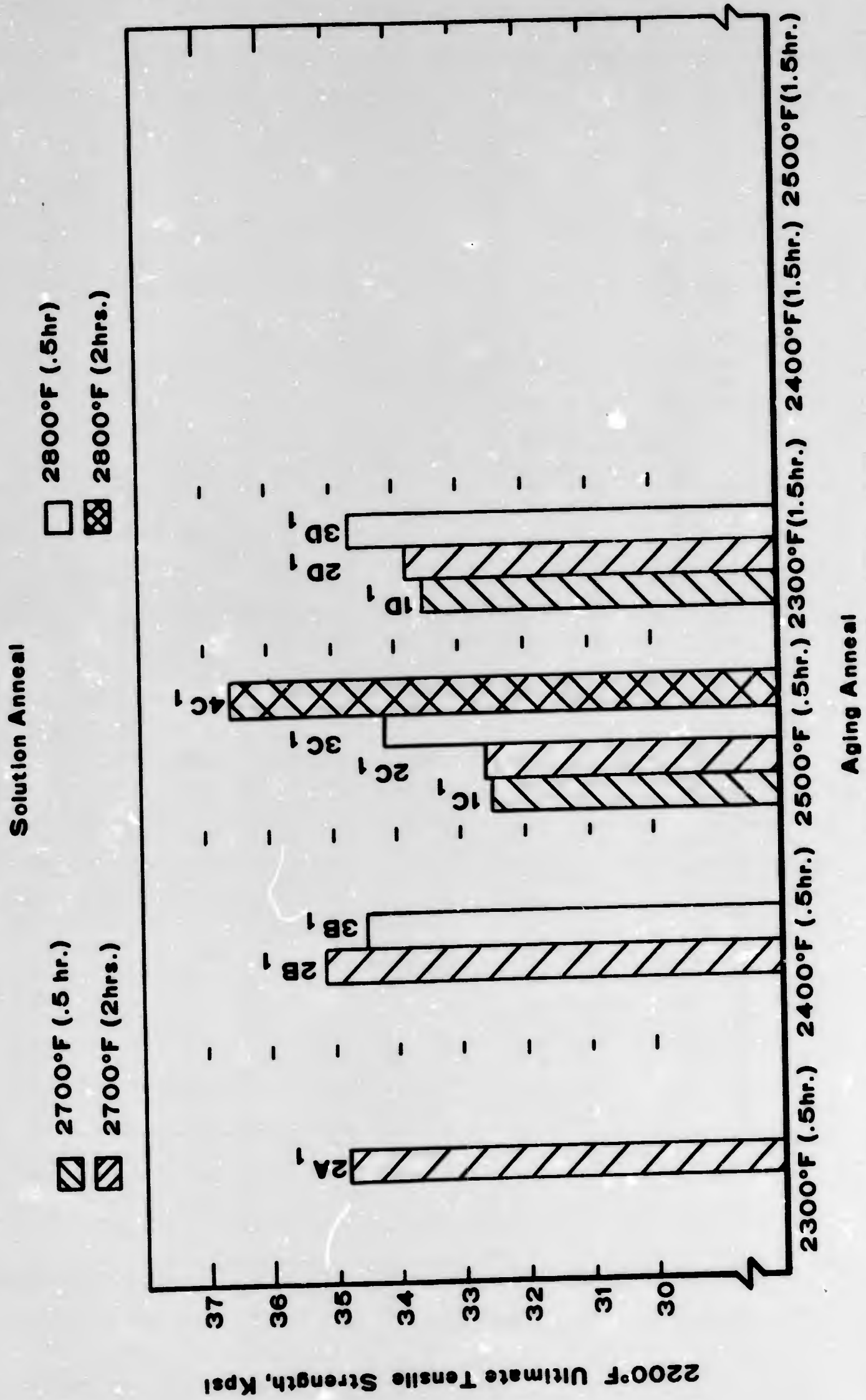


Figure 31

**Ultimate Tensile Strength of Cb-752 Duplex Annealed Sheet  
at 2200°F; Sheet Cold Reduced 40 Percent to  
0.024-inch Prior to Indicated Final Aging Anneals**

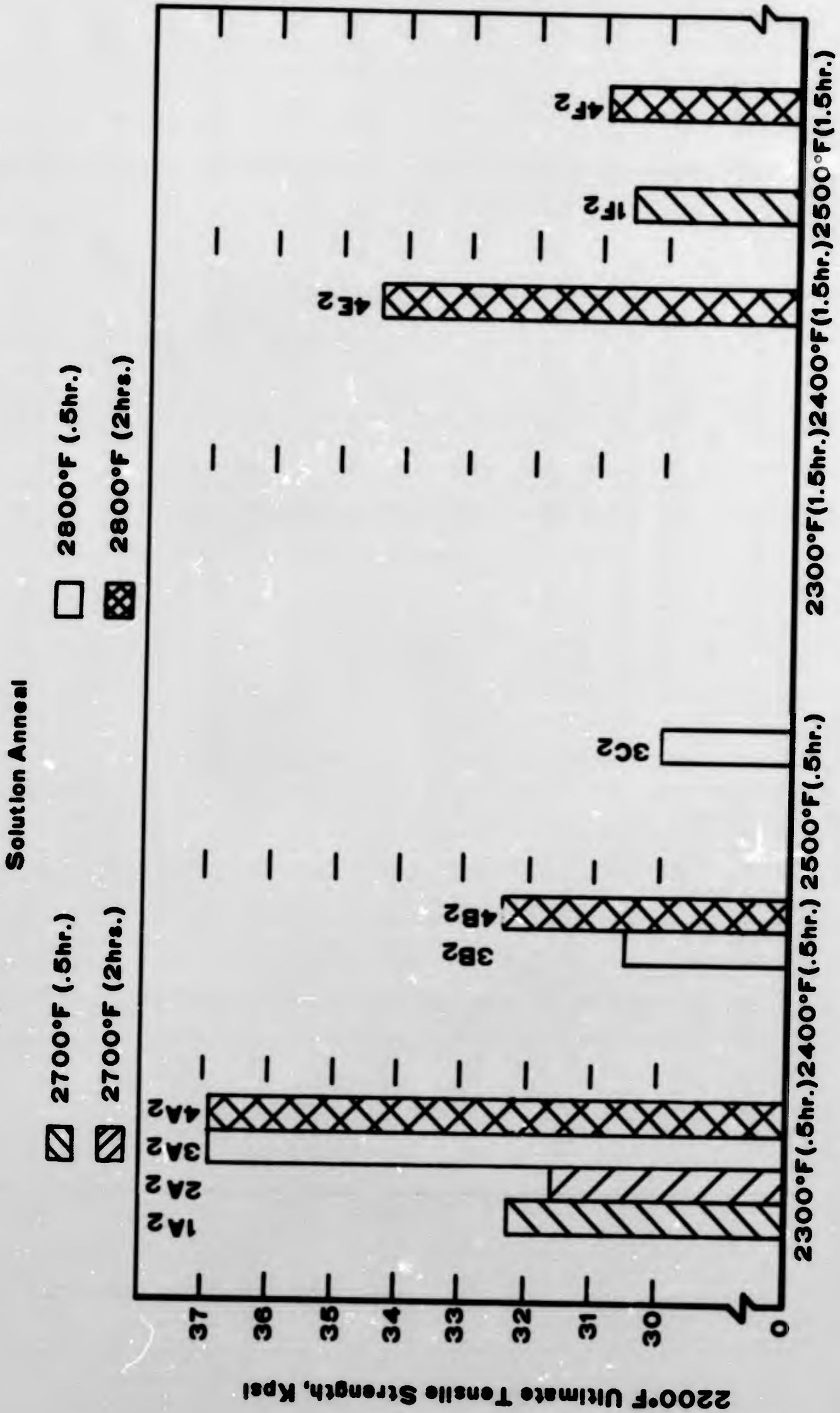


Figure 32

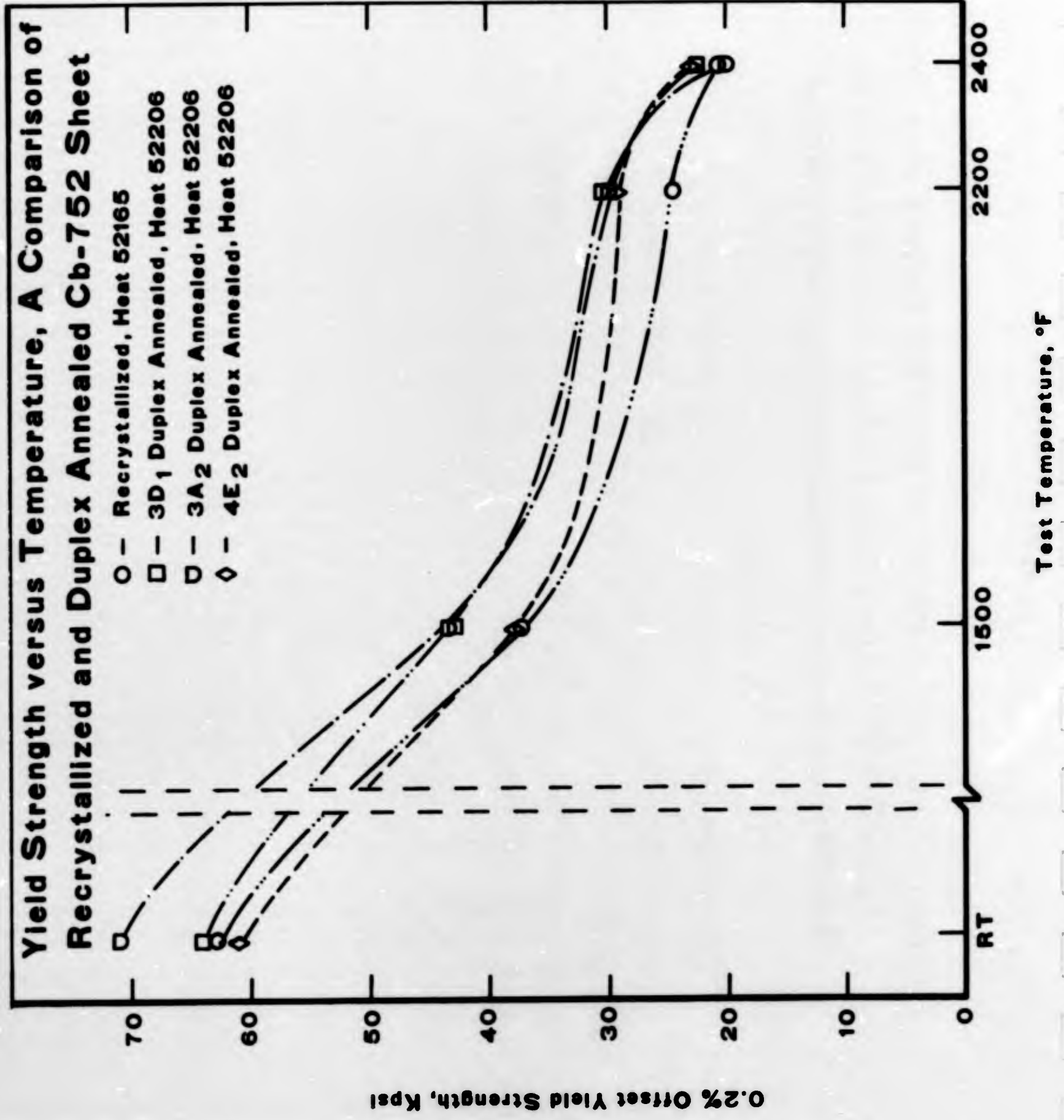


Figure 33

### Ultimate Strength versus Test Temperature, A Comparison of Recrystallized and Duplex Annealed Cb-752 Sheet

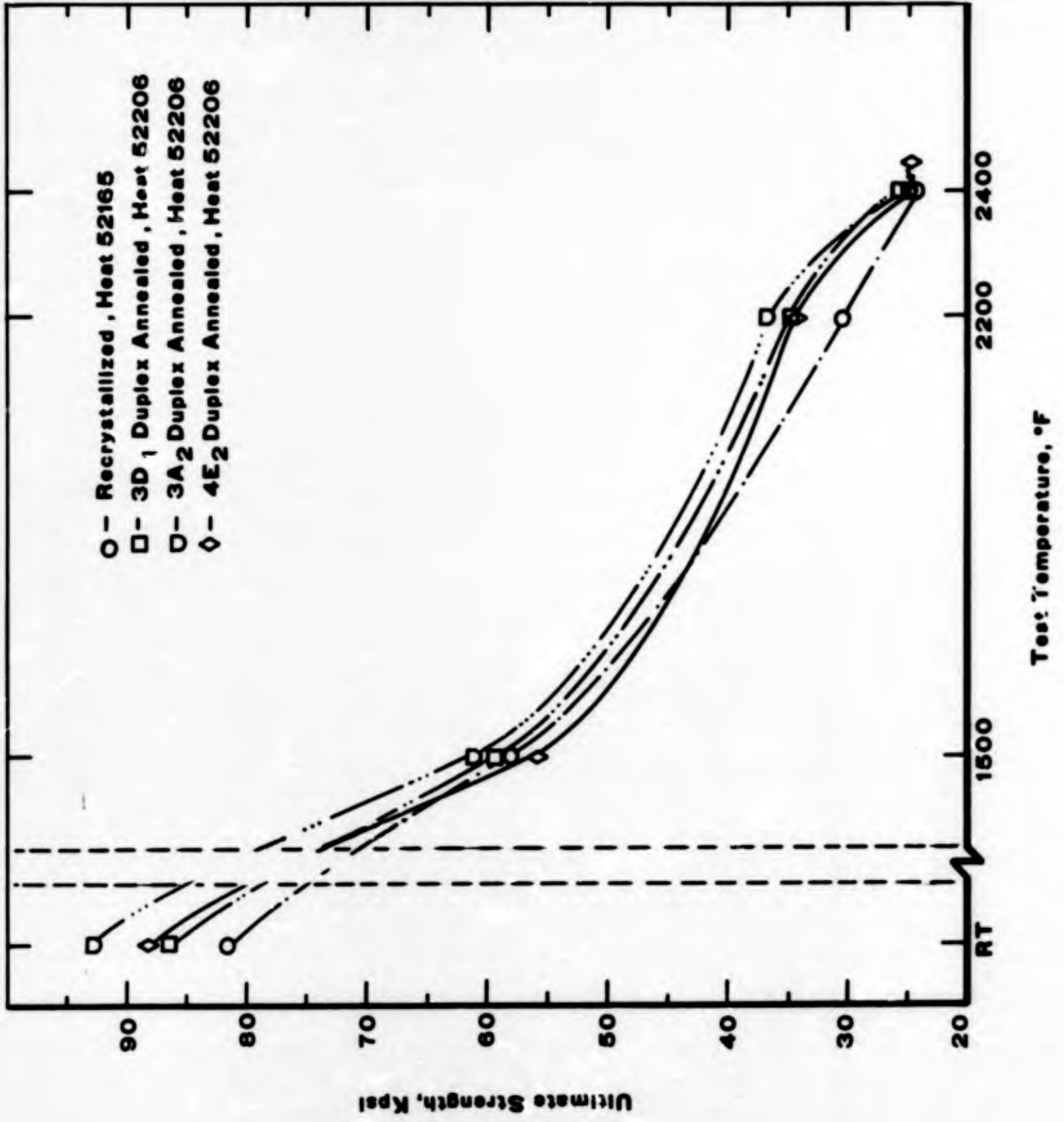
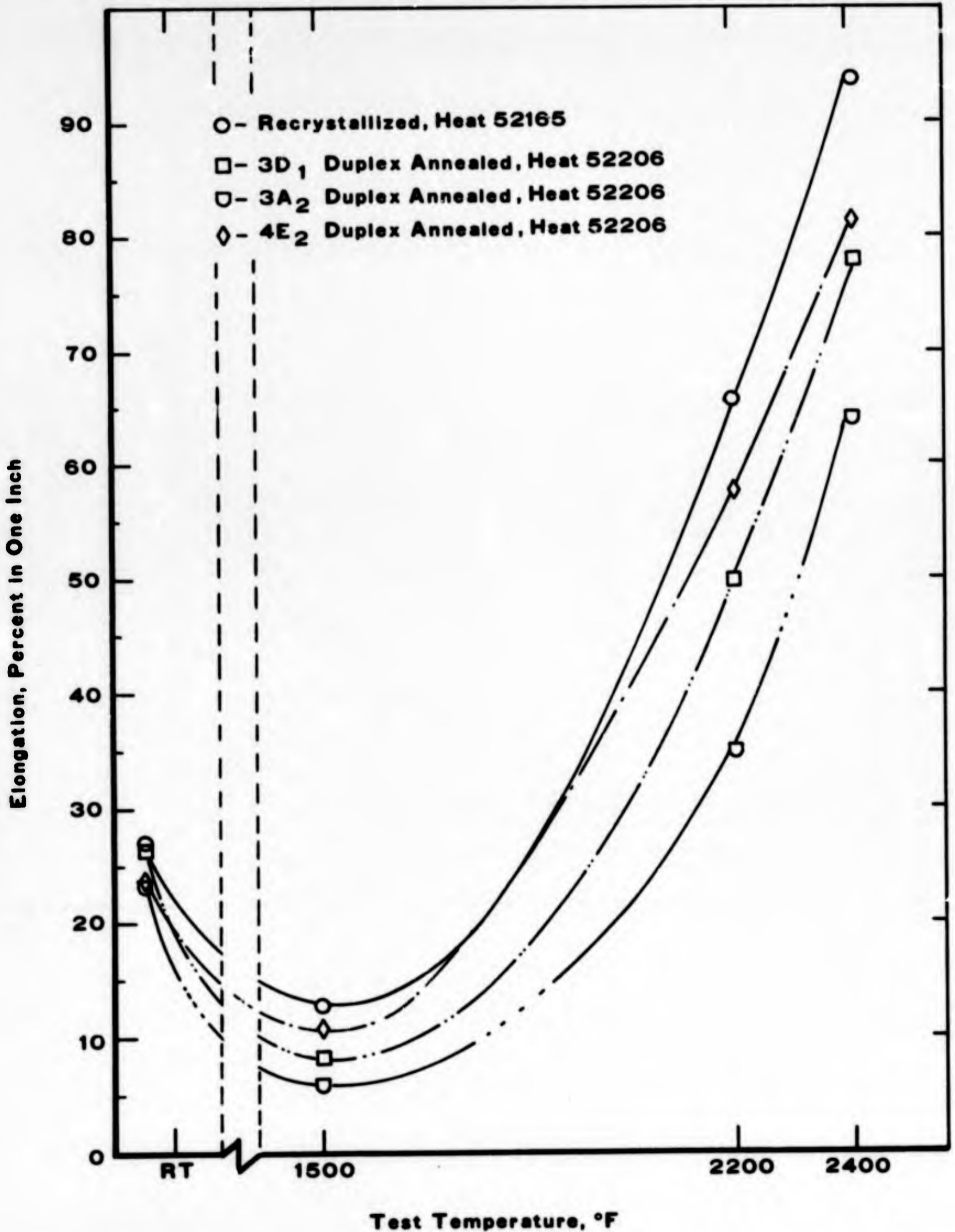
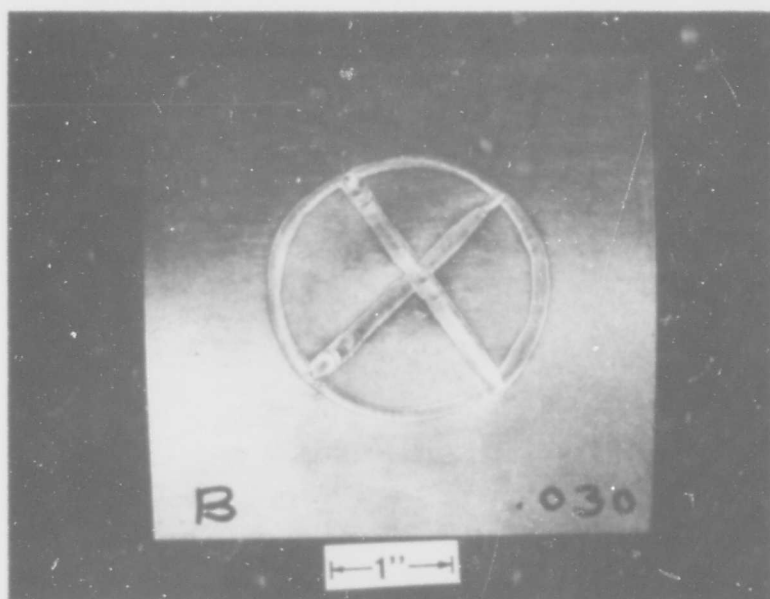


Figure 34

**Elongation versus Temperature , A Comparison of Recrystallized and Duplex Annealed Cb-752 Sheet.**



Neg. No. 13481



Neg. No. 13479

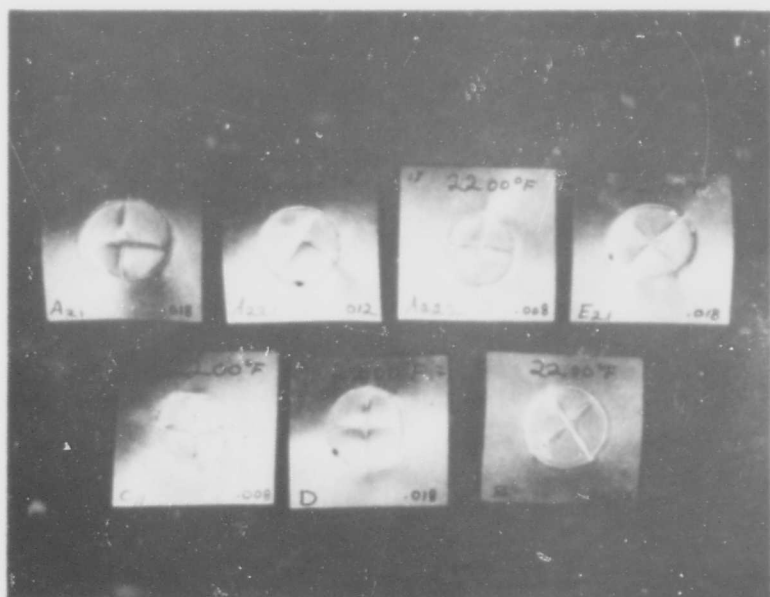


Figure 35: Patch weld test in Cb-752 sheet (Specimens identified as to annealing temperature and sheet thickness).

Metallographer: J. A. Martin  
Reference: J. G. Bewley

TABLE I

SIZES AND WEIGHTS OF 1/4-INCH THICK Cb-752  
SHEET-BAR CHARGED INTO PHASE II OF CONTRACT

<u>Heat No.</u>	<u>Size, Inch</u>	<u>Weight, lb</u>
52165	1/4 x 14-1/4 x 29-1/4	37.00
52206	1/4 x 16-1/4 x 31-1/8	39.30
52206	1/4 x 20-1/4 x 30-1/2	46.50
52206	1/4 x 19 x 30-3/4	40.75
52206	1/4 x 16-1/4 x 30-1/4	40.00
52208	1/4 x 31-3/4 x 38-3/4	102.90
52208	1/4 x 15-3/4 x 31-1/4	50.30
52208	1/4 x 16-1/4 x 30-1/4	51.55
52227	1/4 x 18-3/4 x 30	53.00
52227	1/4 x 19-3/4 x 21-3/4	39.50
52227	1/4 x 14 x 18	22.00
52227	1/4 x 22 x 33-1/4	64.80
52227	1/4 x 19-3/4 x 21-3/4	67.90
52228	1/4 x 15 x 27-1/4	36.90
52228	1/4 x 14-1/2 x 28-1/2	36.80
52228	1/4 x 16 x 26-3/4	40.20
52228	1/4 x 14-1/2 x 25	<u>33.55</u>
		802.95

TABLE II

CHEMICAL ANALYSES OF FIVE HEATS OF Cb-752 USED TO  
PRODUCE 1/4-INCH THICK SHEET-BAR FOR CONTRACT

<u>Heat No.</u>	<u>Chemical Composition*, Weight Percent</u>					
	<u>W</u>	<u>Zr</u>	<u>C</u>	<u>O</u>	<u>H</u>	<u>N</u>
52165	9.8	2.7	0.005	0.0076	0.0011	0.0010
52206	10.0	2.8	0.003	0.0116	0.0008	0.0092
52208	9.9	2.8	0.004	0.0143	0.0008	0.0102
52227**	9.9	2.6	0.003	0.0087	0.0008	0.0067
52228	9.9	2.6	0.004	0.0093	0.0006	0.0080

\* Average of analyses from two or more positions on each heat.

\*\* Prepared from reclaimed Cb-752 scrap.

TABLE III

TYPICAL REDUCTION SEQUENCE EMPLOYED IN ROLLING 1/4-INCH  
Cb-752 SHEET-BAR ON 2-HIGH MILL TO 1/8-INCH THICKNESS

<u>Pass No.</u>	<u>Indicated Reduction, Inch</u>
1	Start
2	--*
3	0.020
4	--
5	0.020
6	--
7	0.020
8	--
9	0.020
10	--
11	0.010
12	--
13	0.010
.	.
.	.
.	.

Same sequence to 1/8-inch thickness

\* Indicates no change in mill setting.

TABLE IV

TYPICAL REDUCTION SEQUENCE USED IN ROLLING 1/8-INCH THICK  
Cb-752 SHEET ON SENDZIMIR MILL TO 0.060-INCH THICKNESS

<u>Pass</u> <u>No.</u>	<u>Indicated Reduction,</u> <u>Inch</u>	<u>Average Sheet Thickness</u> <u>Inch</u>
0	+0.065*	0.133
1	-- **	0.117
2	0.010	0.112
3	0.010	0.105
4	0.008	0.098
5	0.008	0.093
6	0.008	0.088
7	0.006	0.082
8	0.004	0.076
9	0.003	0.073
10	--	0.069
11	--	0.065
12	0.002	0.063
13	0.001	0.060

\* Amount of roll separation above arbitrary "jam" point.

\*\* Indicates no change in mill setting.

TABLE V

SIZES AND WEIGHTS OF Cb-752, 0.060-INCH SHEET ROLLED  
IN PHASE II OF CONTRACT

<u>Heat No.</u>	<u>Sheet No.</u>	<u>Size, (Inch)</u>	<u>Weight (Pounds)</u>
52165	-1	0.060 x 36 x 32-1/2	23.90
52206	-1	0.060 x 30-3/4 x 59-1/2	37.70
	-2	0.060 x 31 x 58-1/2	38.50
	-3	0.060 x 30-1/2 x 58-1/2	37.20
	-4	0.060 x 30-3/4 x 69	44.80
52208	-1	0.060 x 36 x 118	83.00
	-2	0.060 x 30-1/4 x 73	46.70
	-3	0.060 x 31-1/2 x 69-1/2	46.40
52227	-1	0.060 x 30-1/2 x 85	49.60
	-2	0.060 x 28-3/8 x 61	34.80
	-3	0.060 x 25-7/8 x 36-3/4	20.00
	-4	0.060 x 33-3/4 x 86-1/4	59.60
	-5	0.060 x 33 x 95-1/2	61.60
52228	-1	0.060 x 29 x 56	32.40
	-2	0.060 x 28-3/4 x 56	33.20
	-3	0.060 x 32-1/4 x 58-1/4	36.70
	-4	0.060 x 29-1/4 x 51	30.10
Total			716.20

TABLE VI

WEIGHT RECOVERIES ACHIEVED IN ROLLING Cb-752, 1/4-THICK  
SHEET-BAR TO 0.060-INCH THICK SHEET

<u>Item</u>	<u>Weight, Pounds</u>	<u>Recovery</u>	
		<u>Percent</u>	<u>Accumulative Percent</u>
1/4-inch sheet-bar	802.95	--	--
1/8-inch sheet	737.40	92	92
0.060-inch sheet	716.20	97	89

TABLE VII

LIST OF SHEET SIZES AND WEIGHTS SENT TO METALS AND CONTROLS  
COMPANY, MARTIN COMPANY, AND DOUGLAS AIRCRAFT CORPORATION

<u>Company</u>	<u>Heat No.</u>	<u>Size, (Inch)</u>	<u>Weight (Pounds)</u>
Metals and Controls Co. Attleboro, Mass.	52208	0.060 x 12 x RL (3 pcs)	83.0
	52206	0.060 x 12 x 30-3/4 (2 pcs)	15.0
		Total	<u>98.0</u>
Martin Company Denver Division Denver, Colorado	52227	.012 x 30-1/2 x 60-3/4	7.6
	52227	.018 x 30-3/8 x 64	11.3
	52227	.018 x 30-1/2 x 61-1/2	11.2
	52227	.018 x 30-3/8 x 44-1/2	7.85
	52227	.030 x 25-3/8 x 69-1/4	17.55
		Total	<u>55.50</u>
Douglas Aircraft Co. Santa Monica, Calif.	52165	.012 x 19-3/4 x 57	4.1
	52165	.012 x 12 x 59-1/2	2.7
	52165	.012 x 36-1/4 x 60-1/2	8.4
	52165	.012 x 25 x 40-1/2	4.1
	52165	.012 x 25 x 25-1/2	2.55
	52165	.012 x 29-3/4 x 70	8.60
	52165	.012 x 19-3/4 x 25-1/2	1.95
	52165	.012 x 23-1/2 x 29-1/4	2.75
	52227	.012 x 30-1/2 x 14	1.70
	52165	.012 x 10 x 28-1/2	1.12
	52165	.012 x 12 x 28-1/2	1.34
	52165	.012 x 28-1/4 x 30-3/4	3.39
	52165	.018 x 18 x 34	3.60
	52165	.018 x 31-1/4 x 33-3/4	6.10
			Total
GRAND TOTAL			205.90

TABLE VIII

THICKNESS AND THICKNESS VARIATIONS OF Cb-752 SHEET  
SENT TO DOUGLAS AIRCRAFT AND MARTIN COMPANY

<u>Sheet No.</u>	<u>Size (Inch)</u>	<u>Average Thickness (Inch)</u>	<u>Average Variation (Inch)</u>
Douglas	52165 - 1a	.012 x 19-3/4 x 57	0.0116 +.0009 -.0006
	- 1b	.012 x 12 x 59-1/4	0.0118 +.0012 -.0008
	- 1c	.012 x 36-1/4 x 60-1/4	0.0123 +.0002 -.0007
	- A <sub>1</sub>	.012 x 25 x 40	0.0119 +.0006 -.0007
	- A <sub>21</sub>	.012 x 25 x 25-1/2	0.0125 +.0005 -.0005
	- B	.012 x 29-3/4 x 70	0.0124 +.0001 -.0004
	- A <sub>221</sub>	.012 x 19-3/4 x 25-1/2	0.0121 +.0004 -.0001
	- D	.012 x 23-1/2 x 29-1/4	0.0124 +.0006 -.0004
	- C <sub>12</sub>	.012 x 10 x 28-1/2	0.0117 +.0003 -.0007
	- C <sub>22</sub>	.012 x 28-1/4 x 30-3/4	0.0122 +.0008 -.0012
	- C <sub>21</sub>	.012 x 12 x 28-1/2	0.0117 +.0008 -.0007
	52227 - D	.012 x 30-1/2 x 14	0.0123 +.0002 -.0003
	52165 - D <sub>1</sub>	.018 x 18 x 34	0.0177 +.0003 -.0007
	- D <sub>2</sub>	.018 x 31-1/4 x 33-3/4	0.0174 +.0006 -.0004

CONTINUED

TABLE VIII - Continued

<u>Sheet No.</u>	<u>Size (Inch)</u>	<u>Average Thickness (Inch)</u>	<u>Average Variation (Inch)</u>	
Martin { 52227-	1D	.012 x 30-1/2 x 60-3/4	0.0122	+ .0003 - .0006
	- 1A	.018 x 30-3/8 x 64	0.0175	+ .001 - .0005
	- 1B	.018 x 30-1/2 x 61-1/2	0.0178	+ .0007 - .0008
	- 1C	.018 x 30-3/8 x 44-1/2	0.0176	+ .0009 - .0006
	- 3	.030 x 25-3/8 x 69-1/4	0.030	+ .0009 - .001

TABLE IX

HARDNESS, OLSEN CUP TEST RESULTS, AND BEND TEST RESULTS OF Cb-752 DUPLEX ANNEALED SHEET, HEAT 52206

Duplex Annealing Treatment				Final Anneal		Designation	Hardness Rb	Olsen Cup Test Depth	Test Results Type of Failure	Minimum Bend Radius R/T						
Solution Anneal Temp. °F	Time, Hr	Percent	Cold Reduction Gage, inch	Temp. °F	Time, Hr											
2700	1/2	20	0.032	2300	1/2	1A1	89.5	0.3525	ductile	0.030						
						1D1	90	.3250	"	.030						
						1B1	90	.4430	"	.030						
						1E1	89	.2600	"	.030						
						1C1	88.5	.3925	"	.030						
						1F1	91	.3200	"	.030						
	2	40	0.024	2300	1/2	1A2	91	.2550	ductile	.030						
						1D2	89	.3050	"	.030						
						1B2	88	.3430	"	.030						
						1E2	90	.2650	"	.030						
						1C2	88.5	.2825	"	.030						
						1F2	87	.2855	"	.030						
						2700	2	20	0.032	2300	1/2	2A1	90.5	.3275	ductile	.030
												2D1	91	.3200	"	.030
												2B1	92	.4350	"	.030
2800	1/2	20	0.032	2300	1/2	2E1	91	.2450	"	.030						
						2C1	90	.3475	"	.030						
						2F1	90	.3075	brittle	.030						
						2A2	88	.3205	ductile	.030						
						2D2	87	.3100	"	.030						
						2B2	89	.3270	"	.030						
2800	1/2	40	0.024	2400	1/2	2E2	85	.3075	"	.030						
						2C2	89	.2975	"	.030						
						2F2	87	.2925	"	.030						
						3A1	90.5	.3200	brittle	.030						
						3D1	91	.3100	ductile	.030						
						3B1	92	.4030	"	.030						
						3E1	91	.2550	"	.030						
						3C1	91	.3325	"	.030						
						3F1	93	.2900	"	.030						
2800	1/2	40	0.024	2300	1/2	3A2	89	.2975	ductile	.030						
						3D2	89	.2850	"	.030						
						3B2	90	.3360	"	.030						
						3E2	90	.2900	"	.030						
						3C2	88	.2900	"	.030						
						3F2	89	.2850	"	.030						

CONTINUED

TABLE IX - continued

Duplex Annealing Treatment				Test Results						
Solution Anneal Temp., °F	Solution Anneal Time, Hr	Percent Cold Reduction	Final Anneal Temp., °F	Final Anneal Time, Hr	Designation	Hardness Rb	Olsen Cup Test			
							Depth	Type of Failure	Minimum Bend R/T	
2800	2	20	2300	1/2	4A1	91	.2550	brittle	.030	>.060
					4D1	91	.3000	"	.030	>.060
					4B1	92.5	.4030	"	.030	>.120
					4E1	92	.3014	"	.030	>.120
					4C1	91	.2900	"	.030	>.120
					4F1	93	.3125	"	.030	>.120
					4A2	89.5	.2950	ductile	.030	.060
					4D2	90	.1600	"	.030	>.060
					4B2	90	.3240	"	.030	.060
					4E2	91	.2700	"	.030	.120
2500	1-1/2	40	2300	1/2	4C2	89	.2750	"	.030	.060
					4F2	90	.2800	"	.030	.120

TABLE X

## ROOM TEMPERATURE TENSILE PROPERTIES OF Cb-752 DUPLEX ANNEALED SHEET, HEAT 52206

Solution Anneal		Duplex Annealing Treatment				Test Results			
Temp., °F	Time, Hr	Percent Reduction	Cold Reduction	Final Anneal	Designation	Yield Strength 0.2% Offset Kpsi	Ultimate Strength, Kpsi	Elongation Percent in one inch	
		Gage, Inch	Gage, Inch	Temp., °F Time, Hr					
2700	1/2	20	0.032	2300	1/2	1A1	66.5	88.0	27
				2400	1-1/2	1D1	66.0	88.3	23
				2500	1/2	1B1	65.5	86.7	24
				2500	1-1/2	1E1	64.5	86.0	26
				2500	1/2	1C1	62.0	84.4	26
				2500	1-1/2	1F1	58.7	82.1	26
2700	2	40	0.024	2300	1/2	1A2	67.5	89.1	--
				2400	1-1/2	1D2	59.6	84.7	27
				2500	1/2	1B2	59.0	81.8	26
				2500	1-1/2	1E2	58.8	81.8	26
				2500	1/2	1C2	58.5	81.0	24
				2500	1-1/2	1F2	59.6	83.0	28
				2300	1/2	2A1	70.0	89.0	24
				2400	1-1/2	2D1	65.5	87.3	25
				2500	1/2	2B1	66.5	87.7	23
				2500	1-1/2	2E1	64.8	84.7	25
				2500	1/2	2C1	63.1	86.2	27
				2500	1-1/2	2F1	57.8	81.4	28
2800	1/2	20	0.032	2300	1/2	2A2	71.8	89.4	22
				2400	1-1/2	2D2	60.6	84.9	27
				2500	1/2	2B2	57.6	86.9	27
				2500	1-1/2	2E2	59.3	81.5	26
				2500	1/2	2C2	57.7	82.6	28
				2500	1-1/2	2F2	59.0	81.7	27
				2300	1/2	3A1	67.1	88.5	24
				2400	1-1/2	3D1	64.2	86.7	26
				2500	1/2	3B1	66.6	88.2	23
				2500	1-1/2	3E1	63.1	84.7	25
				2500	1/2	3C1	63.3	85.9	24
				2500	1-1/2	3F1	62.1	85.3	27
				2300	1/2	3A2	71.4	92.7	24
				2400	1-1/2	3D2	66.5	89.3	25
				2500	1/2	3B2	64.4	84.3	23
				2500	1-1/2	3E2	61.7	81.4	25
				2500	1/2	3C2	57.9	83.8	29
				2500	1-1/2	3F2	59.4	82.3	27

CONTINUED

TABLE X - continued

Duplex Annealing Treatment						Test Results			
Solution Anneal Temp., °F	Anneal Time, Hr	Percent Reduction	Cold Reduction Gage, Inch	Final Anneal Temp., °F	Final Anneal Time, Hr	Designation	Yield Strength 0.2% Offset Kpsi	Ultimate	
								Strength, Kpsi	Elongation Percent in one inch
2800	2	20	0.032	2300	1/2	4A1	68.3	91.7	23
				2400	1-1/2	4D1	65.1	87.5	26
				2500	1/2	4B1	65.4	88.1	22
					1-1/2	4E1	63.4	85.7	24
					1/2	4C1	64.5	87.8	24
					1-1/2	4F1	62.9	92.2	24
		40	0.024	2300	1/2	4A2	70.7	92.0	23
				2400	1-1/2	4D2	66.7	89.1	23
					1/2	4B2	66.4	89.3	23
				2500	1-1/2	4E2	64.8	88.4	24
					1/2	4C2	62.0	85.5	28
					1-1/2	4F2	60.8	83.5	27

TABLE XI

## ELEVATED TEMPERATURE TENSILE PROPERTIES OF Cb-752 DUPLEX ANNEALED SHEET, HEAT 52206

Solution Anneal Temp., °F	Solution Anneal Time, Hr	Cold Reduction		Final Anneal		Designation	Yield Strength		Ultimate Strength, Kpsi		Elongation					
		Percent	Gage, inch	Temp., °F	Time, Hr		0.2% Offset, Kpsi	2200°F	2400°F	1500°F	2200°F	2400°F	% in one inch			
2700	1/2	20	0.032	2300	1-1/2	1D1	40.4	29.0	20.0	56.7	33.6	24.7	7	62	89	
				2500	1/2	1C1	35.8	27.5	20.0	55.8	32.5	23.7	10	67	75	
2700	1/2	40	0.024	2300	1/2	1A2	40.6	26.5	18.8	61.0	32.3	22.9	9	52	87	
				2500	1-1/2	1F2	--	22.0	--	--	30.5	--	--	--	72	--
	2	20	0.032	2300	1/2	2A1	40.9	30.6	18.2	59.0	34.8	25.5	10	40	90	
				2300	1-1/2	2D1	--	29.6	--	--	33.8	--	--	--	64	--
2400	1/2	20	0.032	2400	1/2	2B1	43.3	29.7	19.1	57.3	35.1	25.1	8	56	84	
				2500	1/2	2C1	--	26.8	--	--	32.6	--	--	--	65	--
2800	1/2	40	0.024	2300	1/2	2A2	--	25.9	--	--	31.6	--	--	30	--	
				2300	1-1/2	3D1	42.7	29.7	21.6	58.9	34.7	25.8	8	50	76	
	2400	1/2	20	0.032	2400	1/2	3B1	41.4	30.8	21.3	58.6	34.5	26.0	8	45	80
					2500	1/2	3C1	37.6	28.7	22.4	56.5	34.2	25.9	10	55	84
	2300	1/2	40	0.024	2300	1/2	3A2	43.6	30.4	20.0	61.3	36.9	24.6	6	35	64
					2400	1/2	3B2	--	23.6	--	--	30.5	--	--	--	61
2500	1/2	20	0.032	2500	1/2	3C2	--	23.3	--	--	30.0	--	--	66	--	
				2500	1/2	4C1	38.4	32.6	22.2	57.0	36.6	26.6	9	50	83	
2800	1/2	40	0.024	2300	1/2	4A2	43.4	30.4	18.7	58.8	36.9	25.6	7	48	71	
				2400	1/2	4B2	--	28.0	--	--	32.4	--	--	--	52	--
	2400	1-1/2	20	0.032	2400	1-1/2	4E2	37.7	28.6	21.9	56.2	34.4	23.7	11	58	82
					2500	1/2	4F2	--	25.3	--	--	30.9	--	--	61	--

TABLE XII

CREEP-RUPTURE PROPERTIES OF Cb-752 SHEET IN FIVE SELECTED DUPLEX ANNEALED CONDITIONS  
TESTED AT 2200°F UNDER 15,000 PSI STRESS, HEAT 52206

<u>Solution Anneal</u> <u>Temp., °F</u>	<u>Anneal</u> <u>Time, Hr</u>	<u>Percent</u> <u>Reduction</u>	<u>Aging Anneal</u> <u>Temp., °F</u>	<u>Time, Hr</u>	<u>Sheet</u> <u>Designation</u>	<u>Rupture</u> <u>Life, Hr</u>	<u>Total</u> <u>Elongation, Percent</u>	<u>Reduction in</u> <u>Area, Percent</u>	<u>Time for Five Percent</u> <u>Elongation, Hr</u>
2700	2	20	2300	1/2	2A <sub>1</sub>	13.1 37.9	69 65	69 70	1.0 1.5
2700	2	20	2400	1/2	2B <sub>1</sub>	16.5	57	60	1.9
2800	1/2	20	2400	1/2	3B <sub>1</sub>	23.6 18.9	36 100	70 78	1.1 2.4
2800	1/2	20	2500	1/2	3C <sub>1</sub>	18.3 22.7	64 68	78 73	0.67 4.4
2800	2	40	2400	1-1/2	4E <sub>2</sub>	12.3 19.2	70 97	76 70	1.5 3.3

TABLE XIII

CREEP-RUPTURE PROPERTIES OF RECRYSTALLIZED AND STRESS-RELIEVED Cb-752 SHEET TESTED AT  
2400°F UNDER 10,000 PSI STRESS, HEAT 52165

<u>Sheet No.</u>	<u>Thickness (Inch)</u>	<u>Final Reduction (Percent)</u>	<u>Annealing Temp. (°F)</u>	<u>Rupture Life (Hrs)</u>	<u>Minimum Creep Rate (inch/inch/hour)</u>	<u>Total Elongation (Percent)</u>
E <sub>1</sub>	0.030	50	2200	25*	0.015	88
				12.1	.050	94
B	0.030	75	2200	26.7*	.005	38
				21.8	.0142	57
A <sub>1</sub>	0.030	88	2200	9.2	.030	49
				7.2	.032	37
D	0.018	60	2200	22.8	.011	62
				22.8	.011	62
E <sub>21</sub>	0.018	70	2200	6.5	.056	97
				20	.0153	65
A <sub>21</sub>	0.018	93	2200	5.1	.044	40
				25*	.006	21
A <sub>221</sub>	0.012	96	2200	25*	.0083	36
				6.6	.0148	19
C <sub>11</sub>	0.008	50	2200	1.0	--	15
				1.3	--	7
E <sub>22</sub>	0.008	87	2200	3.9	.095	40
				2.2	.053	16
A <sub>222</sub>	0.008	97	2200	22.6	.0026	9
E <sub>1</sub>	0.030	50	2000	25.8	.018	61
				22.5	.009	37
B	0.030	75	2000	23.6	.008	41
				24.1	.015	61
A <sub>1</sub>	0.030	88	2000	25.0*	.005	18
				25.0*	.004	15
D	0.018	60	2000	23.0	.011	55
				20.8	.015	52

CONTINUED

TABLE XIII - continued

<u>Sheet No.</u>	<u>Thickness (Inch)</u>	<u>Final Reduction (Percent)</u>	<u>Annealing Temp. (°F)</u>	<u>Rupture Life (Hrs)</u>	<u>Minimum Creep Rate (inch/inch/hour)</u>	<u>Total Elongation (Percent)</u>
E <sub>21</sub>	0.018	70	2000	26.9*	.009	33
				24.1	.009	23
A <sub>21</sub>	0.018	93	2000	0.2	>.2	11
				0.6	>.2	12
A <sub>221</sub>	0.012	96	2000	5.7	.134	84
				5.3	.086	58
C <sub>11</sub>	0.008	50	2000	25.2	.0085	57
				25.0*	--	13
E <sub>22</sub>	0.008	87	2000	12.0	.009	19
				19.7	.017	37
A <sub>222</sub>	0.008	97	2000	12.7	.0157	32
				25.0*	--	--

\* Tests interrupted before rupture at times indicated.

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