SAE Aerospace
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AEROSPACE STANDARD

SAE AS1814C

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Superseding AS1814B

Terminology for Titanium Microstructures

RATIONALE

AS1814C results from a five year review and update of this specification.

1. SCOPE

1.1 This list of terms, with accompanying photomicrographs where appropriate, is intended as a guide for use in the preparation of material specifications.

1.2 The terms and photomicrographs are intended to present definitions only; they do not define either acceptance limits or minimum standards of quality.

1.3 Listings are not grouped by specific alloys or conditions and represent the typical microstructures wherever they occur.

1.4 Etchants used for the microstructures shown are stated. Where "Krolls" is stated, the composition is 10 ml HF, 30 ml HNO_3, and 50 ml water (H_2O).

1.5 Other common etchants are listed in ASTM E 407, Microetching Metals and Alloys.

2. TERMINOLOGY

2.1 Acicular Alpha

A product of nucleation and growth or an athermal (martensitic) transformation from beta to the lower temperature allotropic alpha phase. It may be needle-like, lenticular, or flattened bar morphology in three dimensions. Its typical aspect ratio is about 10:1. (Figure 1)

2.2 Aged Beta

A beta matrix in which alpha, typically fine, has precipitated as a result of aging or cooling from a temperature high in the alpha-beta phase field. (Figure 2).

2.3 Alpha

The low temperature allotrope of titanium with a hexagonal, close-packed crystal structure. (Figure 3)

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2.4 Alpha 2 Structure

A structure consisting of an ordered alpha phase, such as Ti_3 (Al, Sn) found in highly stabilized alpha. Defined by selected area diffraction, not optical metallography.

2.5 Alpha-Beta Structure

A microstructure which contains both alpha and beta as the principal phases at a specific temperature. It is composed of alpha, transformed beta, and retained beta. Structure shown in Figure 4 is typical of mill annealed Ti 6Al-4V; similar structure shown in Figure 18 is more typical of recrystallization annealed Ti 6Al-4V.

2.6 Alpha Case

The oxygen, enriched, alpha-stabilized surface which results from elevated temperature exposure to environments containing oxygen or air. (Figures 5A and 5B) Alpha case is normally hard, brittle, and considered detrimental.

2.7 Alpha Prime

A supersaturated, acicular nonequilibrium hexagonal phase formed by a diffusionless transformation of the beta phase. It occurs when cooling rates are too high to permit transformation by nucleation and growth. It exhibits an aspect ratio of 10:1 or greater. Also known as martensite or martensite alpha. (Figure 6)

2.8 Alpha Double Prime (Orthorhombic Martensite)

A supersaturated nonequilibrium orthorhombic phase formed by a diffusionless transformation of the beta phase in certain alloys. It occurs when cooling rates are too high to permit transformation by nucleation and growth. It may be strain induced during working operations and may be avoided by appropriate in-process annealing treatments.

2.9 Alpha Stabilizer

An alloying element which dissolves preferentially in the alpha phase and raises the alpha-beta transformation temperature. Aluminum is the most commonly used alpha stabilizer. Interstitial elements such as oxygen and nitrogen are also potent alpha stabilizing elements.

2.10 Alpha Stringer

Platelet alpha that has been elongated and distorted by metal working but not broken up or recrystallized. Also called "Wormy Alpha" or “Stringy Alpha”. (Figure 19).

2.11 Alpha-Transus

The temperature that alpha begins to revert to beta.

2.12 Basketweave

Alpha platelets, with or without interweaved beta platelets, that occur in colonies. Also known as Widmanstatten. Forms during cooling through the beta transus at intermediate cooling rates. (Figure 7A)

2.13 Beta

The allotrope of titanium with a body-centered cubic crystal structure occurring at temperatures between the solidification of molten titanium and the beta transus, i.e., the high temperature allotrope.

2.14 Beta Eutectoid Stabilizer

An alloying element that dissolves preferentially in the beta phase, lowers the alpha-beta to beta transformation temperature, under equilibrium conditions, and results in the beta decomposition to alpha plus a compound. This is a eutectoid reaction. Commonly used beta eutectoid forming elements are iron, nickel, chromium, and manganese.

2.15 Beta Fleck

Beta flecks have reduced amounts of, or no, primary alpha which may exhibit a morphology different from the primary alpha in the surrounding alpha-beta matrix and/or absence of alpha stabilizers such as oxygen or aluminum. The flecks are then seen by the reduced or lack of alpha within the beta fleck. (Figure 8)

2.16 Beta Isomorphous Stabilizer

An alloying element that is soluble in beta titanium in all proportions. It lowers the alpha-beta to beta transformation temperature without a eutectoid reaction and forms a continuous series of solid solutions with beta titanium. Commonly used beta isomorphous forming elements are vanadium, molybdenum, and zirconium.

2.17 Beta Transus

The temperature that designates the phase boundary between the alpha plus beta and beta fields. Commercially pure grades transform in a range of 1630 to 1760 °F (890 to 960 °C) depending upon oxygen and iron content. In general, aircraft alloys vary in transformation temperature from 1380 to 1900 °F (750 to 1040 °C).

2.18 Blocky Alpha

Alpha phase which is considerably larger and more polygonal in appearance than the primary alpha present. It may be induced by metal working and has an aspect ratio of 3:1 or higher although its aspect ratio may be near 1:1 (less common). It may result from extended exposure high in the alpha-beta phase field following rapid or slow cooling through the beta transus during forging or heat treating operations. It may be removed by beta recrystallization or by all-beta working followed by further alpha-beta work. May accompany grain boundary alpha or even have its origin as large grain boundary alpha or coarse alpha platelets. Microhardness not significantly different from surrounding normal alpha-beta matrix. (Figure 9)

2.19 Colonies

Regions within prior beta grains with alpha platelets having nearly identical orientations. In commercially pure titanium, colonies often have serrated boundaries. Colonies arise as transformation products during cooling from the beta field at cooling rates slow enough to allow platelet nucleation and growth. (Figures 7A and 7B)

2.20 Elongated Alpha

The hexagonal crystal phase appearing as stringer-like arrays, considerably larger in appearance than the primary alpha. Commonly exhibits an aspect ratio of 3:1 or higher. (Figures 10 and 11)

2.21 Equiaxed Structure

A polygonal or spheroidal microstructural feature having approximately equal dimensions in all directions. In alpha-beta titanium alloys, such a term commonly refers to a microstructure in which most of the alpha phase appears spheroidal, primarily in the transverse direction. (Figures 3, 4, and Figure 18)

2.22 Frequency of Occurrence

A referee determination by viewing 50 fields, 4 in x 5 in (102 mm x 127 mm), projected at 100X. The number of fields containing the feature of interest is divided by the total number of fields viewed to represent the lot, thus arriving at a percentage.

2.23 Gamma Structure

An ordered structure of titanium-aluminum compound with a stoichiometric ratio TiAl and face-centered tetragonal crystal structure.

2.24 Globular Alpha

A spheroidal form of equiaxed alpha. (Figure 4)

2.25 Grain Boundary Alpha

Alpha outlining prior beta grain boundaries. It may be continuous unless broken up by subsequent work. Also may accompany blocky alpha. Occurs by slow cooling from the beta field into alpha-beta field. (Figures 1, 7B, 9, 11, and 12)

2.26 High Aluminum Defect (HAD)

An aluminum-rich alpha stabilized region containing an abnormally large amount of aluminum which may extend across a large number of beta grains. It contains an inordinate fraction of primary alpha but has a microhardness only slightly higher than the adjacent matrix. These are also known as Type II defects. (Figures 13 and 14)

2.27 High Density Inclusion (HDI)

A region with a concentration of elements, usually tungsten, molybdenum, tungsten carbide, or residuals of high melting point master alloys containing molybdenum, having a higher density than the matrix. Regions are readily detectable by X-ray and will appear brighter than the matrix.

2.28 High Interstitial Defect (HID)

Interstitially stabilized alpha phase region of substantially higher hardness and lower ductility than surrounding material. It arises from melting titanium in the presence of nitrogen, oxygen, or carbon. HID typicaly have a diffusion zone. They are commonly called Type I defects or low-density inclusions (LDI). HIDs often associated with voids and cracks. (Figures 15 and 16)

2.29 Hydride Phase

The phase TiH_x formed in titanium when the hydrogen content exceeds the solubility limit. Hydrogen and, therefore, hydrides tend to accumulate at areas of high residual tensile stresses. (Figures 17A and 17B)

2.30 Interstitial Element

An element with relatively small atomic diameter that can assume position in the interstices of the titanium crystal lattice. Common examples are oxygen, nitrogen, hydrogen, and carbon.

2.31 Intergranular Beta

Beta phase situated between alpha grains. It may be at grain corners as in the case of equiaxed alpha type of microstructures in alloys having low beta stabilizer content. Because it is the original phase from which alpha is formed, it is usually the continuous phase in two phase microstructures. (Figure 18)

2.32 Intermetallic Compound

A phase in an alloy system which usually occurs at a definite atomic ratio and exhibits a narrow solubility range, such as Ti_2Fe, Ti-Ni, or alpha 2. Nearly all such phases are brittle.

2.33 Martensite

See "Alpha Prime", “Alpha Double Prime” (orthorhombic martensite in some significantly beta stabilized alloys).

2.34 Matrix

The constituent which forms the continuous phase of a two or more phase microstructure.

2.35 Metastable Beta

A nonequilibrium phase composition that can be partially transformed to martensite, alpha, or eutectoid decomposition products with thermal or strain energy activation during subsequent processing or service exposure.

2.36 Mf

The temperature at which the martensite reaction is complete.

2.37 Ms

The maximum temperature at which a martensite reaction begins upon cooling from the beta phase or high in the alpha-beta field.

2.38 Omega

A nonequilibrium, submicroscopic phase which can be formed either athermally or isothermally preceding the formation of alpha from beta. It occurs in metastable beta alloys, alpha-plus-beta alloys rich in beta content, and CP titanium, and leads to severe embrittlement in metastable beta alloys or alpha-beta alloys rich in beta content. Athermal omega is believed to form without change in composition and is analagous to martensite. Isothermal omega is generally formed by aging a retained beta structure in the 392 to 932 °F (200 to 500 °C) temperature range.

2.39 Ordered Structure

The orderly or periodic arrangement of solute atoms on the lattice sites of the solvent.

2.40 Platelet Alpha

A relatively coarse acicular alpha, usually with low aspect ratios. This microstructure arises from cooling alpha or alpha-beta alloys at a slow rate from temperatures that a significant fraction of beta phase exists. (Figure 10)

2.41 Primary Alpha

The allotrope of titanium with a hexagonal, close-packed crystal structure which is retained from the last high temperature alpha-beta heating. (Figure 4)

2.42 Prior Beta Grain Size

Size of beta grains established during the most recent beta field excursion. The grains may be distorted by subsequent subtransus deformation. The beta grain boundaries may be obscured by a superimposed alpha-beta microstructure and detectable only by special techniques. (Figure 12)

2.43 Stringy Alpha

See “Alpha Stringer”. (Figure 19)

2.44 Substitutional Element

An alloying element with an atom size and other features similar to the titanium atom, which can replace or substitute for the titanium atoms in the lattice and form a significant region of solid solution in the phase diagram. Such elements used in alloying titanium include but are not limited to aluminum, vanadium, molybdenum, chromium, iron, tin, and zirconium.

2.45 Transformed Beta

A local or continuous structure comprised of decomposition products arising either by martensitic or by nucleation and growth processes during cooling from either above the beta transus or some temperature high in the alpha-beta phase field. The structure typically consists of alpha platelets which may or may not be separated by beta phase.

2.46 Twin

Two portions of a crystal having a definite crystallographic relationship; one may be regarded as the parent, the other as the twin. The orientation of the twin is either a mirror image of the orientation of the parent about a "twinning plane" or an orientation that can be derived by rotating the twin portion about a "twinning axis". (Figure 3)

2.47 Widmanstatten Structure

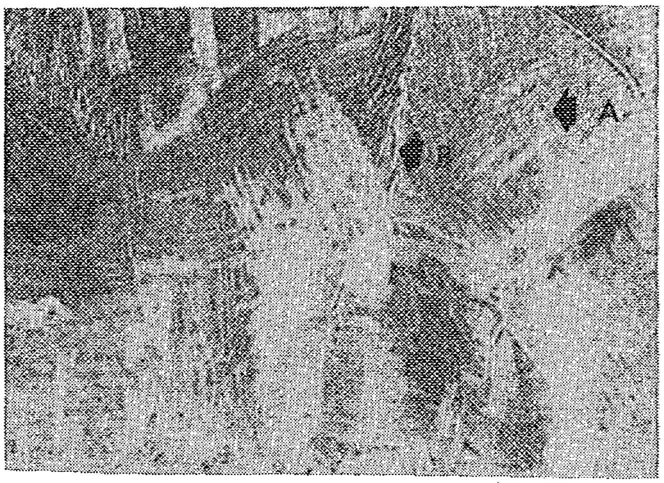
See "Basketweave".

2.48 Wormy Alpha

See “Alpha Stringer”. (Figure 19)

3. NOTES

3.1 The change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document.



ETCHANT: KROLL'S 100X

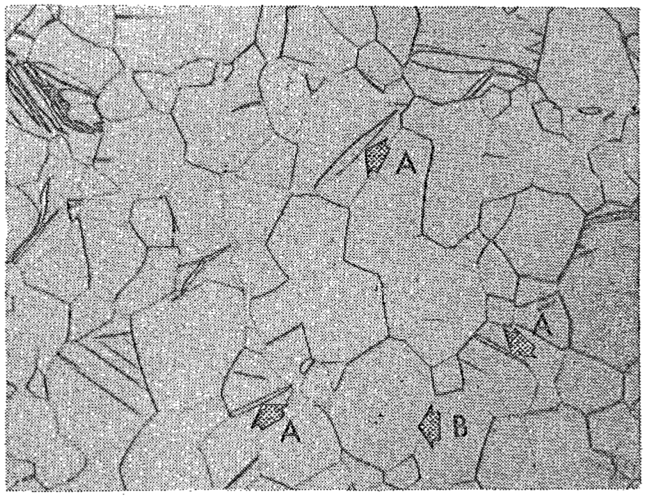
ALLOY 6Al-2Sn-4Zr-2Mo. ACICULAR ALPHA COLONIES IN PRIOR BETA GRAINS "A" WITH SOME GRAIN BOUNDARY ALPHA "B".

FIGURE 1

ETCHANT: KROLL'S 500X

ALLOY 15V-3Cr-3Al-3Sn AGED BETA. BETA MATRIX WITH ALPHA PRECIPITATES. SOLUTION ANNEALED AT 1450°F (788°C), AIR COOLED, AGED AT 950°F (510°C), 8 HOURS.

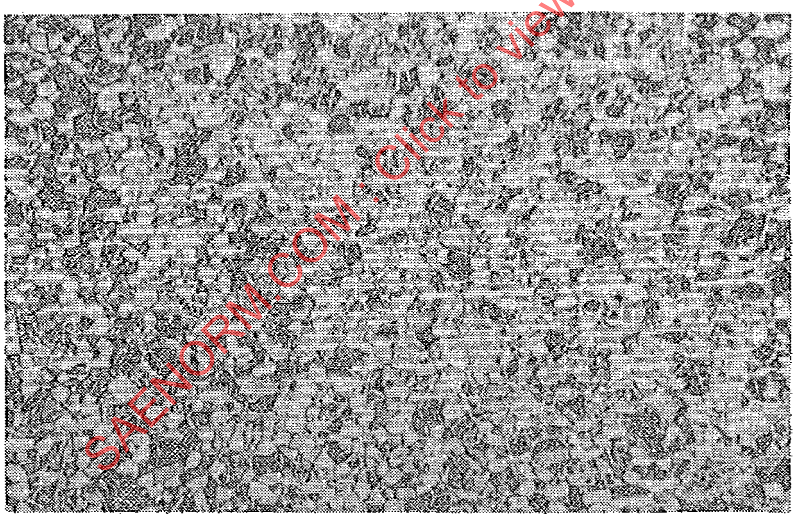
FIGURE 2



ETCHANT: KROLL'S 250X

ALLOY COMMERCIALLY PURE. (Ti-35A) TWIN "A" IN EQUIAXED ALPHA "B"

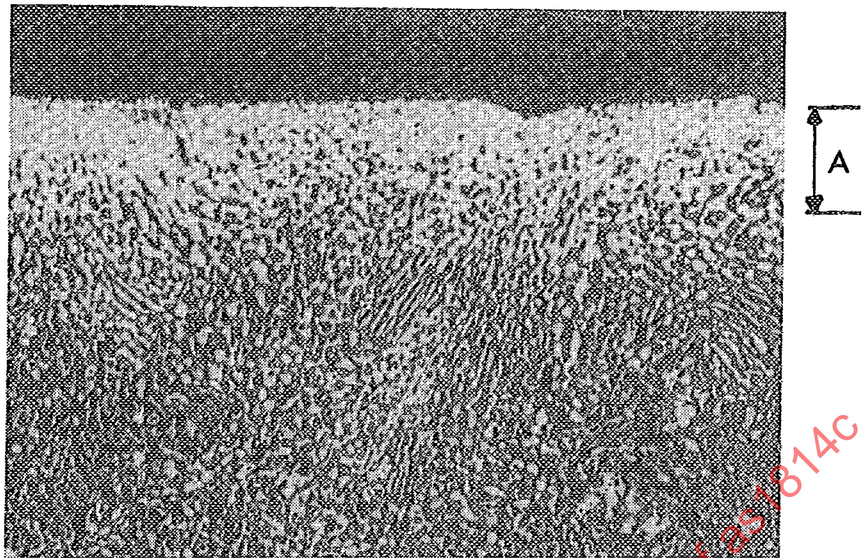
FIGURE 3



ETCHANT: KROLL'S X200

ALLOY 6AL-4V. PRIMARY ALPHA (LIGHT ETCHING) IN A TRANSFORMED BETA MATRIX (DARK ETCHING)

FIGURE 4



ETCHANT: 2% HF IN SAT. SOL'N OXALIC ACID 100X

ALLOY 6Al-2Sn-4Zr-2Mo. ALPHA CASE "A" ON ALPHA BETA ALLOY.

FIGURE 5A

ETCHANT: KROLL'S 100X

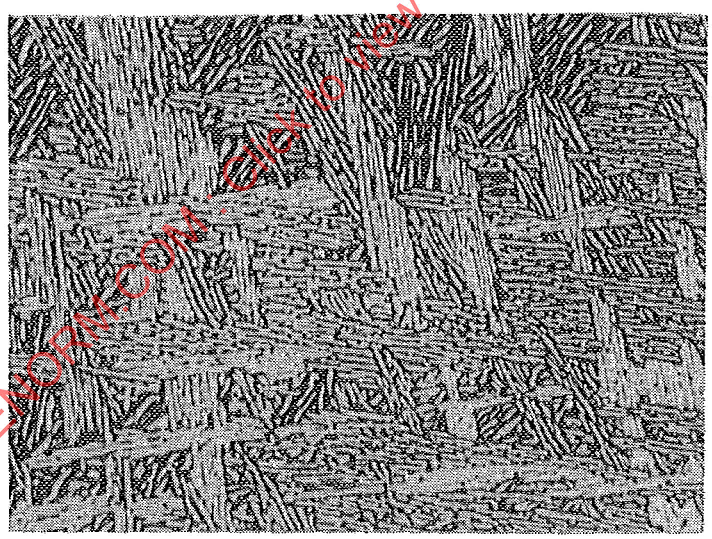
ALLOY 15V-3Cr-3Sn-3Al. ALPHA CASE "A" ON BETA ALLOY.

FIGURE 5B

ETCHANT: 1-1/2% HF, SAT. OXALIC ACID 200X

ALLOY 6Al-4V
ALPHA PRIME (MARTENSITE)

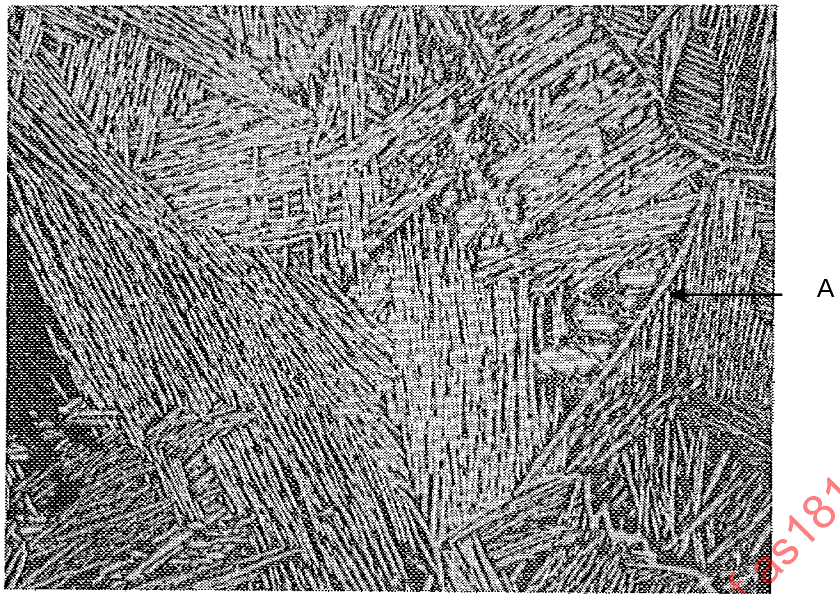
FIGURE 6



ETCHANT: KROLL'S 100X

ALLOY 6Al-4V. BASKETWEAVE IN PLATE.

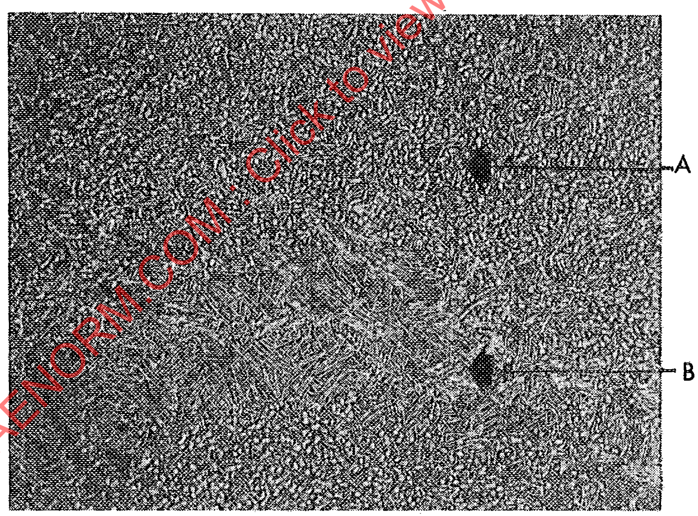
FIGURE 7A - COLONIES OF ALPHA IN BASKETWEAVE STRUCTURE



ETCHANT: KROLL'S PLUS AMMONIUM BIFLUORIDE 200X

ALLOY 6Al-4V CAST-HOT ISO-STATIC PRESSED AT 1750°F (954°C), 2 HR, AND FURNACE COOLED.

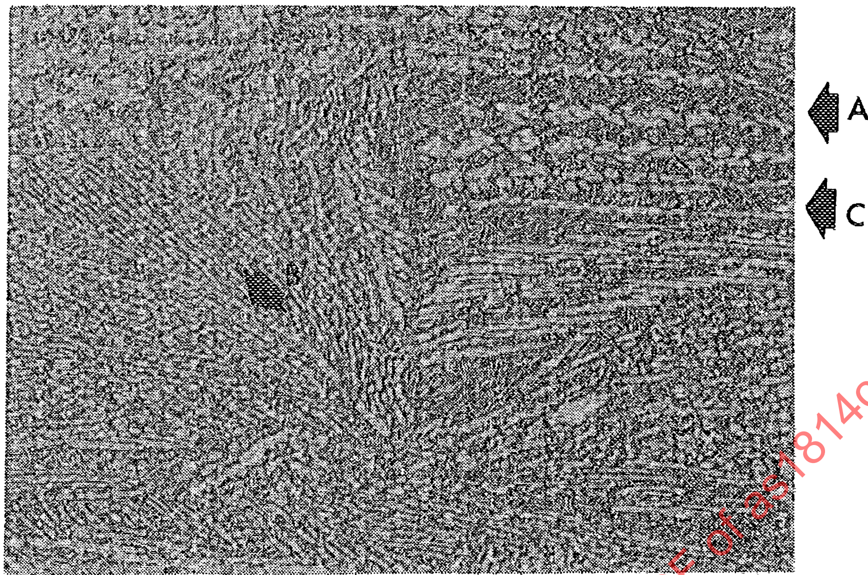
FIGURE 7B - COLONIES OF ALPHA IN BASKETWEAVE STRUCTURE WITH “A” GRAIN BOUNDARY ALPHA



ETCHANT: 1-1/2% HF IN SAT. SOLUTION OXALIC ACID. 100X

ALLOY 6Al-4V. BETA FLECK "B" IN ALPHA-BETA MATRIX "A".

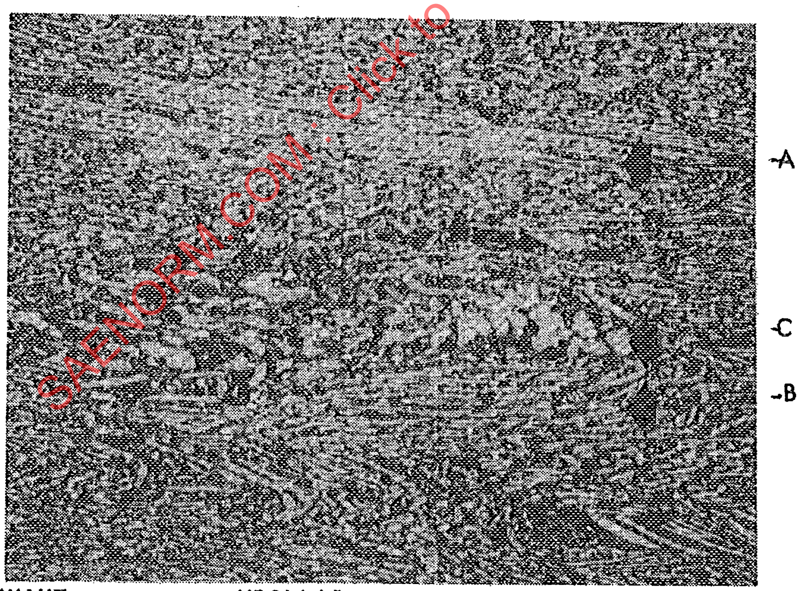
FIGURE 8



ETCHANT: KROLL'S 100X

ALLOY 6A1-4V. BLOCKY ALPHA "A" WITH GRAIN BOUNDARY ALPHA "B" AND ELONGATED ALPHA "C".

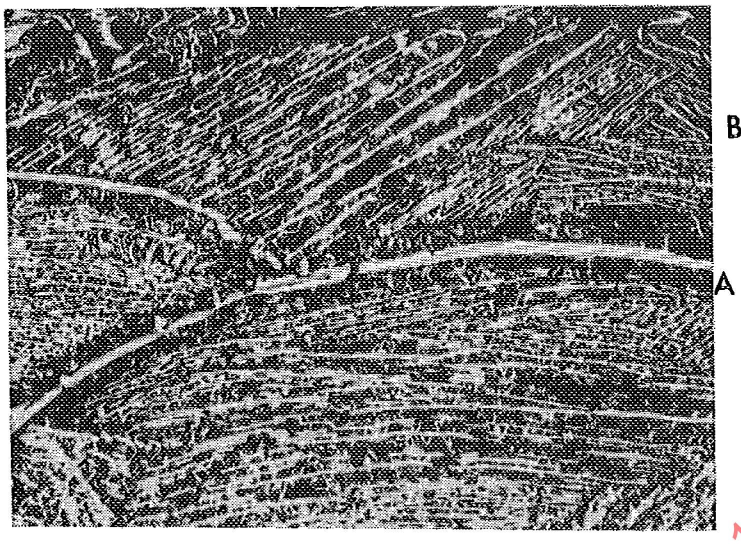
FIGURE 9



ETCHANT: KROLL'S 100X

ALLOY 6A1-4V. ELONGATED ALPHA "A" AND PLATELET ALPHA "B" TYPICAL OF ORIENTED ALPHA. BLOCKY ALPHA "C" IS SEEN IN THE CENTRAL AREA (ALSO KNOWN AS GLOBULAR ALPHA).

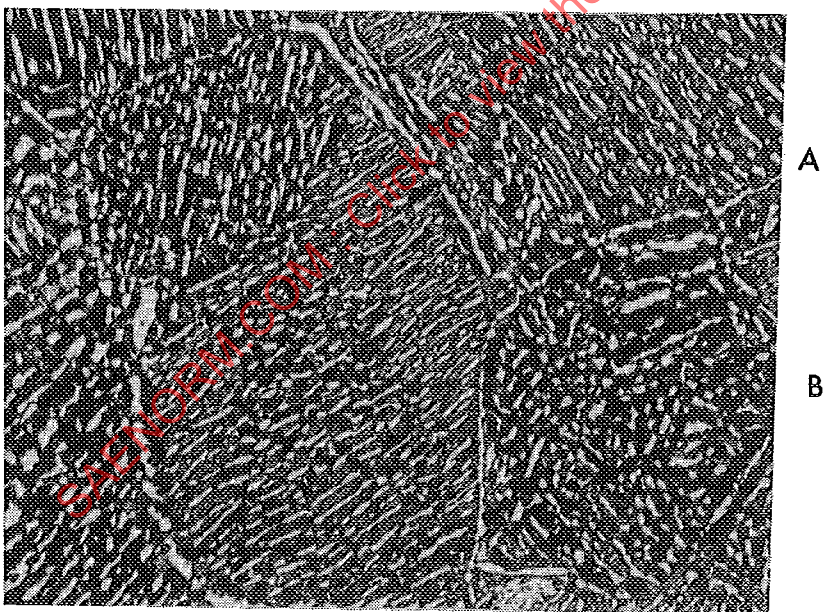
FIGURE 10



ETCHANT: KROLL'S 100X

ALLOY 6Al-2Sn-4Zr-6Mo. GRAIN BOUNDARY ALPHA "A" WITH ELONGATED ALPHA "B".

FIGURE 11



ETCHANT: KROLL'S 100X

ALLOY 6Al-2Sn-4Zr-6Mo. GRAIN BOUNDARY ALPHA "A" SURROUNDING PRIOR BETA GRAINS "B".

FIGURE 12