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TERMINOLOGY FOR TITANIUM MICROSTRUCTURES

1. SCOPE:

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

1.2 Ø 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 Ø 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 Ø Other common etchants are listed in ASTM E407, Microetching Metals and Alloys.

2. TERMINOLOGY:

2.1 Ø Acicular Alpha: A product of nucleation and growth or a thermal (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. (Fig. 1)

2.2 Ø Aged Beta: A beta matrix in which alpha, typically fine, has precipitated as a result of aging. (Fig. 2)

2.3 Ø Alpha: The allotrope of titanium with a hexagonal, close-packed crystal structure. (Fig. 3)

2.4 Ø Alpha 2 Structure: A structure consisting of an ordered alpha phase, such as Ti_3 (Al,Sn) found in highly stabilized alpha. Defined by X-ray diffraction, not optical metallography.

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

2.6 Alpha Case: The oxygen, nitrogen, or carbon enriched, alpha-stabilized
Ø surface which results from elevated temperature exposure to environments containing these elements. (Fig. 5A & 5B) Alpha case is normally hard, brittle, and considered detrimental.

2.7 Alpha Prime: A supersaturated, acicular non-equilibrium hexagonal alpha
Ø 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. (Fig. 6)

2.8 Alpha Double Prime (Orthorhombic Martensite): A supersaturated
Ø non-equilibrium 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 alloy element which dissolves preferentially in the
Ø 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-Transus: The temperature which designates the phase boundary between the alpha and alpha-plus-beta fields.

2.11 Basketweave: Alpha platelets, with or without interleaved beta platelets,
Ø that occur in colonies. Also known as Widmanstatten. Forms during cooling through the beta transus at intermediate cooling rates. (Fig. 7A, 7B)

2.12 Beta: The allotrope of titanium with a body-centered cubic crystal
Ø structure occuring between the solidification of molten titanium and the beta transus.

2.13 Beta Eutectoid Stabilizer: An alloying element that dissolves
Ø 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 and can be very sluggish for some alloys. Commonly used beta eutectoid forming elements are iron, chromium, and manganese.

2.14 Beta Fleck: Transformed alpha-lean and/or beta-rich region in the
Ø alpha-beta microstructure. This area has a beta transus measurably below that of the matrix. Beta flecks have reduced amounts of primary alpha which may exhibit a morphology different from the primary alpha in the surrounding alpha/beta matrix. (Fig. 8)

2.15 Ø **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 elements are vanadium and molybdenum.

2.16 Ø **Beta Transus**: The minimum temperature above which equilibrium alpha transforms to beta. Commercially pure grades transform in a range of 1630° - 1760°F (890° - 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).

2.17 Ø **Blocky Alpha**: Alpha phase which is considerably larger and more polygonal in appearance than the primary alpha present. It is induced by unidirectional metal working and has an aspect ratio of 3:1 or higher. It may result from extended exposure high in the alpha-beta phase field following rapid 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. Micro-hardness not significantly different from surrounding normal alpha-beta matrix. (Fig. 9)

2.18 Ø **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. (Figs. 7A, 7B, 10)

2.19 Ø **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. (Fig. 10 and 11)

2.20 Ø **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. (Fig. 3 and 4)

2.21 Ø **Frequency of Occurrence**: A referee determination by viewing 50 fields, 4 x 5 in. (100 x 125 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.

2.22 **Gamma Structure**: An ordered structure of titanium-aluminum compound with a stoichiometric ratio TiAl and face-centered tetragonal crystal structure.

2.23 Ø **Globular Alpha**: A spheroidal form of equiaxed alpha occurring in a nonuniform microstructure "Equiaxed Structure". (Fig. 4 and 10)

2.24 Ø **Grain Boundary Alpha**: Primary or transformed 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. (Fig. 1, 7B, 11, and 12)

2.25 Ø <u>High Aluminum Defect (HAD)</u>: 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. (Fig. 13 and 14)

2.26 Ø <u>High Density Inclusion (HDI)</u>: A region with a concentration of elements, usually tungsten or columbium, having a higher density than the matrix. Regions are readily detectable by X-ray and will appear brighter than the matrix.

2.27 Ø <u>High Interstitial Defect (HID)</u>: Interstitially stabilized alpha phase region of substantially higher hardness than surrounding material. It arises from very high local nitrogen, oxygen, or carbon concentrations which increase the beta transus and produce the high hardness, often brittle, alpha phase. Their boundaries are always diffused. They are commonly called Type I defects or low-density inclusions (LDI). Defects often associated with voids and cracks. (Fig. 15 and 16)

2.28 Ø <u>Hydride Phase</u>: 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 stresses. (Fig. 17A and 17B)

2.29 Ø <u>Interstitial Element</u>: 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.

2.30 <u>Intergranular Beta</u>: 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. (Fig. 18)

2.31 Ø <u>Intermediate Phase</u>: A distinguishable homogeneous phase whose composition range does not extend to any of the pure components of the system, such as TiH and TiO.

2.32 <u>Intermetallic Compound</u>: A phase in an alloy system which usually occurs at a definite atomic ratio and exhibits a narrow solubility range, such as Ti_2Fe. Nearly all such phases are brittle.

2.33 Ø <u>Isolated</u>: A metallographic feature that occurs in 3% or less of the microstructure.

2.34 Ø <u>Martensite</u>: See "Alpha Prime".

2.35 <u>Matrix</u>: The constituent which forms the continuous or dominant phase of a two or more phase microstructure.

2.36 <u>Metastable Beta</u>: A beta phase composition that can be partially or completely transformed to martensite, alpha, or eutectoid decomposition products with thermal or strain energy activation during subsequent processing or service exposure.

2.37 Mf: The temperature at which the martensite reaction is complete.

2.38 Ms: The maximum temperature at which a martensite reaction begins upon
Ø cooling from the beta phase.

2.39 Occasional: A metallographic feature that occurs in 10% or less of the
Ø microstructure.

2.40 Omega: A non-equilibrium, submicroscopic phase often thought to be a
Ø transition phase which forms as a nucleation growth product during the formation of alpha from beta. It occurs in metastable beta alloys and alpha-plus-beta alloys rich in beta content, and leads to severe embrittlement. It typically occurs during aging at low temperatures but can also be induced by high hydrostatic pressures.

2.41 Ordered Structure: The orderly or periodic arrangement of solute atoms on the lattice sites of the solvent.

2.42 Orientation Alpha: A non-uniform alpha structure that results from
Ø colonies or domains of platelets or wormy alpha lying at different angles such that different areas exhibit different aspect ratios and alpha grain outlines. (Fig. 10 is a typical example.)

2.43 Platelet Alpha: A relatively coarse acicular alpha, usually with low
Ø aspect ratios. This microstructure arises from cooling alpha or alpha-beta alloys at a slow rate from temperatures at which a significant fraction of beta phase exists. (Fig. 10)

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

2.45 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. (Fig. 12)

2.46 Regrowth Alpha: Alpha that grows on pre-existing (primary) alpha during
Ø cooling from high in the alpha-beta field.

2.47 Stringy Alpha: Platelet alpha that has been elongated and distorted by
Ø non-directional metal working but not broken up or recrystallized. Also called "Wormy Alpha". (Fig. 19)

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

2.49 Transformed Beta: A local or continuous structure comprised of decomposition products arising either by martensitic or by nucleation and growth processes during cooling from above the local or overall beta transus. Primary and regrowth alpha may be present. Transformed beta typically consists of alpha platelets which may or may not be separated by beta phase.

2.50 Ø 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". (Fig. 3)

2.51 Ø Widmanstatten Structure: See "Basketweave".

2.52 Ø Wormy Alpha: See "Stringy Alpha". (Fig. 19)

3. NOTES:

3.1 Marginal Indicia: The phi (Ø) symbol is used to indicate changes and additions to the text from the previous issue of this standard.

This standard is under the jurisdiction of AMS Committee "G".

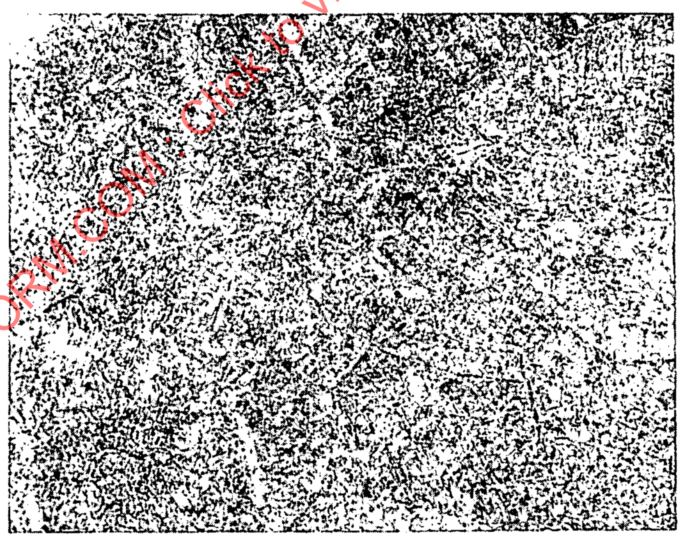
Ø

ETCHANT: KROLL'S 100X

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

FIG. 1

Ø

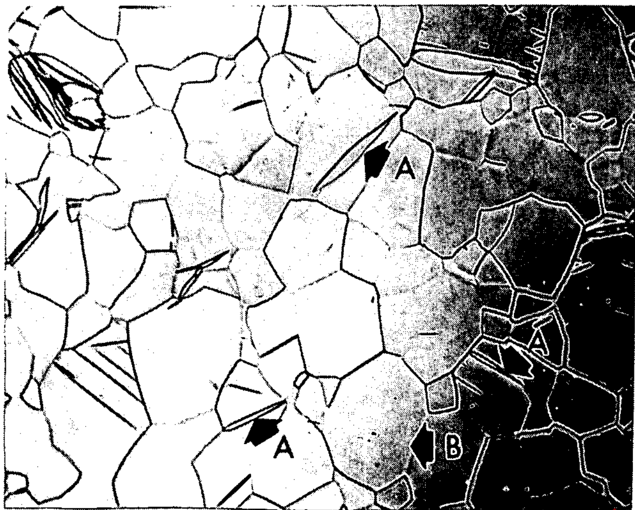


ETCHANT: KROLL'S 500X

ALLOY 15V-3Cr-3Al-3Sn AGED BETA. BETA MATRIX WITH ALPHA PRECIPITATES. SOLUTION ANNEALED AT 1450°F (790°C), AIR COOLED, AGED AT 950°F (510°C), 8 HOURS.

FIG. 2

Ø

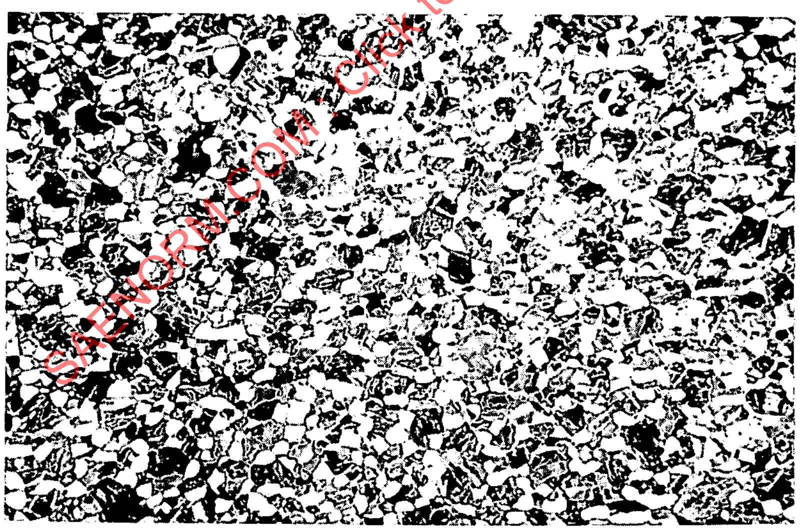


ETCHANT: KROLL'S 250X

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

FIG. 3

Ø

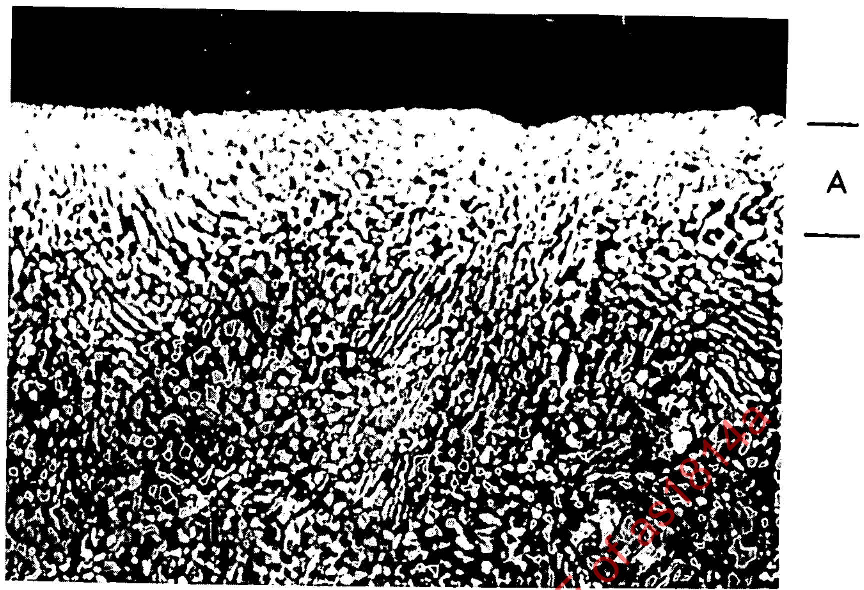


ETCHANT: KROLL'S 200X

ALLOY 6Al-4V. EQUIAXED ALPHA (LIGHT ETCHING) PLUS TRANSFORMED BETA (DARK ETCHING).

FIG. 4

Ø

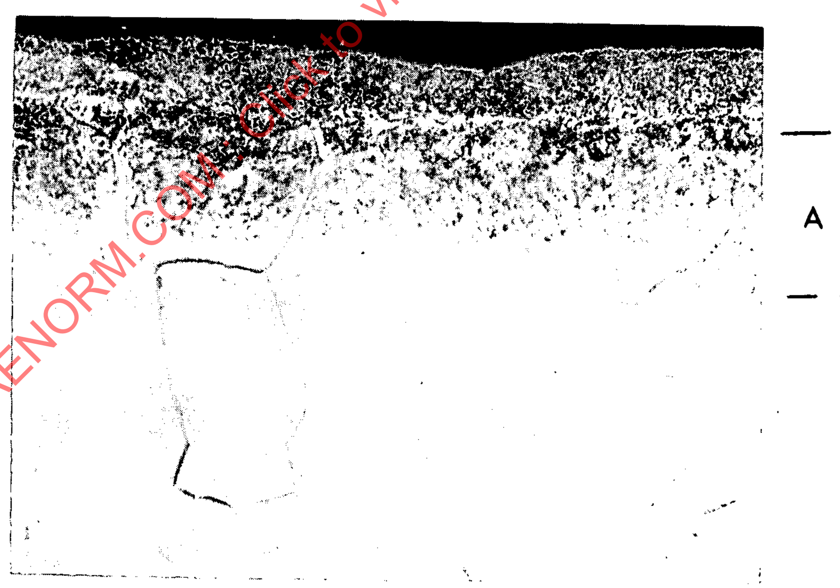


ETCHANT: 2% HF IN SAT. SOL'N OXALIC ACID 100X

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

FIG. 5A

Ø



ETCHANT: KROLL'S 100X

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

FIG. 5B

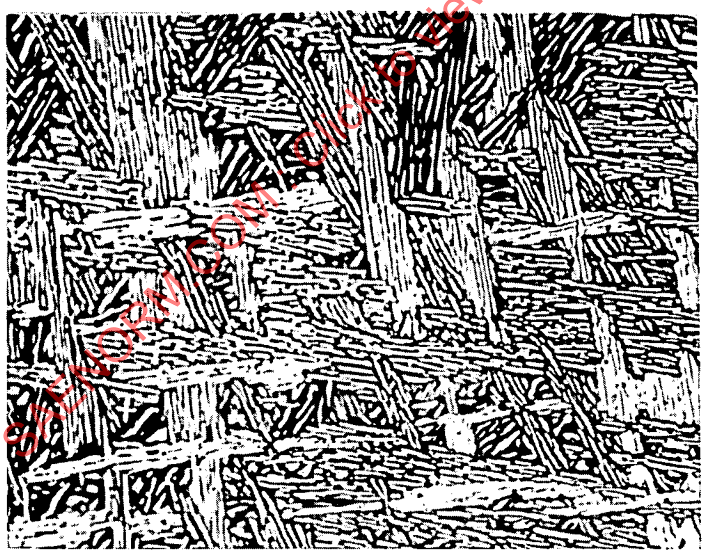
Ø

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

ALLOY 6Al-4V
ALPHA PRIME (MARTENSITE)

FIG. 6

Ø



ETCHANT: KROLL'S 100X

ALLOY 6Al-4V. BASKETWEAVE IN PLATE.

FIG. 7A

Ø

ETCHANT: KROLL'S PLUS AMMONIUM BIFLUORIDE 200X

ALLOY 6Al-4V CAST-HOT ISO-STATIC PRESSED AT 1750°F (955°C), 2 HR, AND FURNACE COOLED.

FIG. 7B

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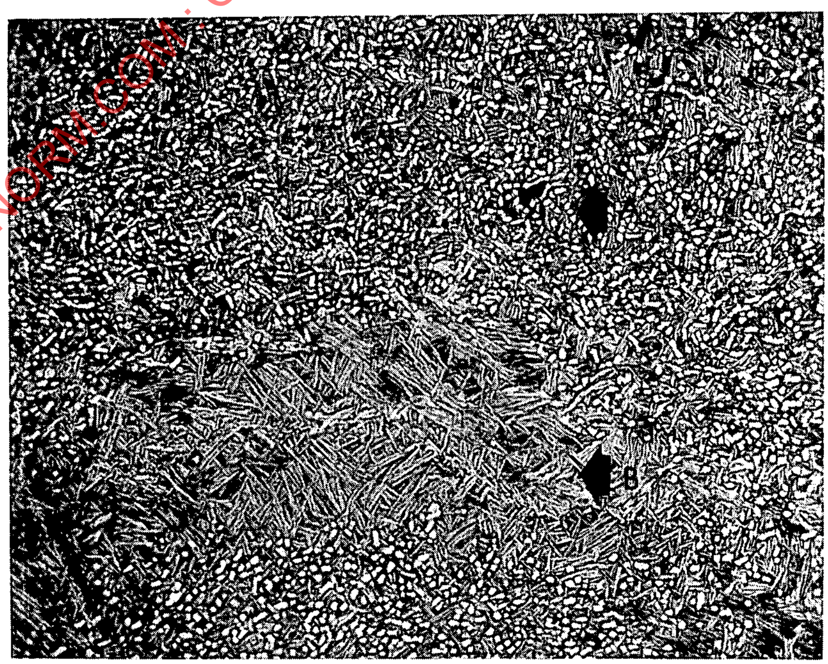
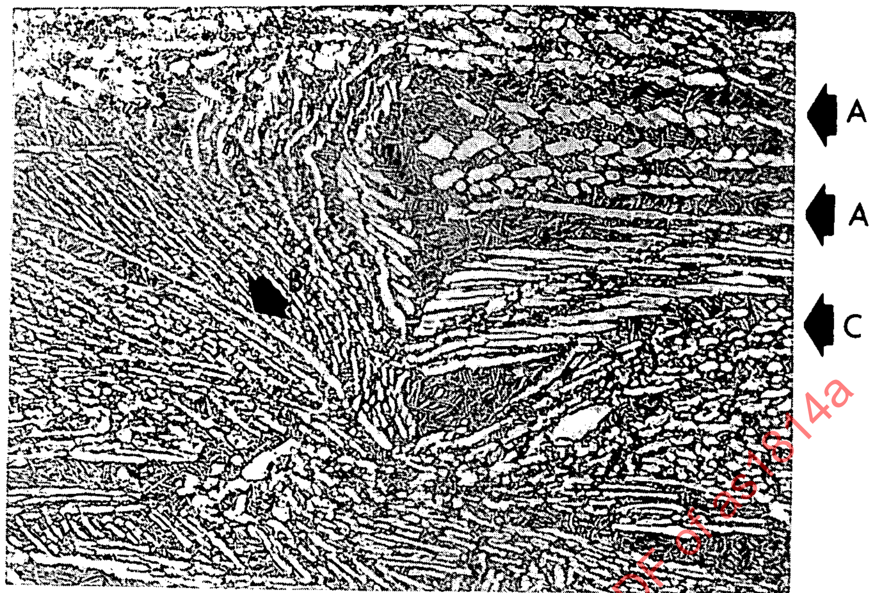


ETCHANT: 1-1/2% HF IN SAT. SOLUTION OXALIC ACID. 100X

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

FIG. 8



ETCHANT: KROLL'S 100X

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

FIG. 9

ETCHANT: KROLL'S 100X

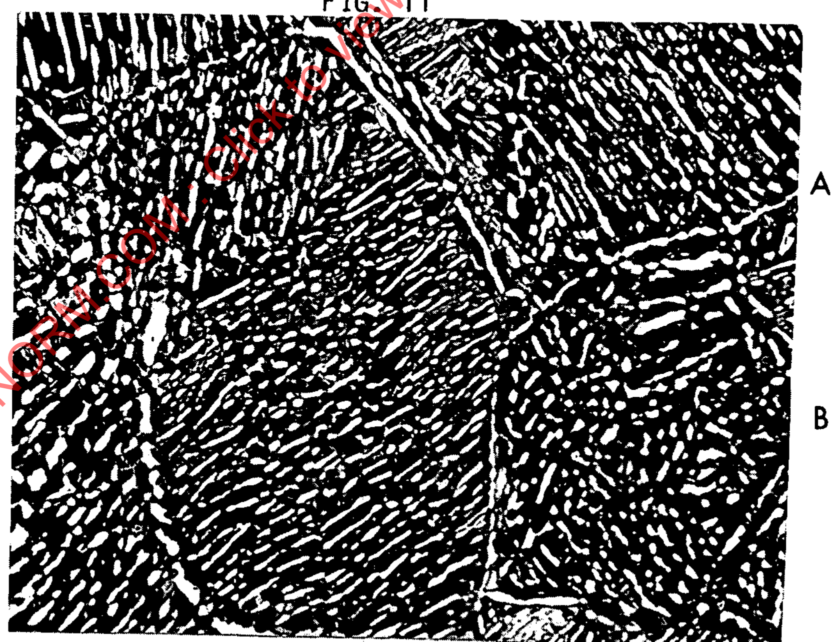
ALLOY 6Al-4V. ELONGATED ALPHA "A" AND PLATELET ALPHA "B" TYPICAL OF ORIENTED ALPHA. BLOCKY ALPHA "C" IS SEEN IN THE CENTRAL AREA (ALSO KNOWN AS GLOBULAR ALPHA).

FIG. 10

ETCHANT: KROLL'S 100X

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

FIG. 11



ETCHANT: KROLL'S 100X

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

FIG. 12