Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

AEROSPACE MATERIAL SPECIFICATION

AMS 2380

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Revised

APPROVAL AND CONTROL OF PREMIUM-QUALITY TITANIUM ALLOYS

1. SCOPE:

1.1 Purpose: This specification covers the procedures for approval of products of premium-quality titanium-base alloys and the controls to be exercised in producing such products.

1.2 Application: For critical, highly-stressed parts of titanium-base alloys which require approval of the product and facets of its production to assure that production lots of the product are of the same metallurgical quality and are produced by the same basic procedures as the products originally qualified; applicable to parts subjected to rigid inspection standards throughout manufacture from ingot to finished part.

1.3 Classification: This specification covers two grades of premium-quality titanium-base products based on the melting practice used in making the alloy, as follows:

Grade 1 - Double Vacuum Melted
Grade 2 - Triple Vacuum Melted

1.3.1 Either grade may be furnished unless a specific grade is specified.

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Material Specifications (AMS) shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 SAE Publications: Available from Society of Automotive Engineers, Inc., Two Pennsylvania Plaza, New York, New York 10001.

2.1.1 Aerospace Material Specifications:

AMS 2350 - Standards and Test Methods
AMS 2631 - Ultrasonic Inspection of Titanium Alloys
AMS 2642 - Structural Examination of Titanium Alloys, Etch-Anodize Inspection Procedure
AMS 2643 - Structural Examination of Titanium Alloys, Chemical Etch Inspection Procedure

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103.

ASTM B299 - Titanium Sponge
ASTM E120 - Chemical Analysis of Titanium and Titanium-Base Alloys

3. TECHNICAL REQUIREMENTS:

3.1 Ingot: Shall be produced as specified herein under effective controls of all variables of the melting processes to consistently produce uniform ingots which will yield products which shall meet the requirements of this specification and shall be procured only from approved sources (see 4.4).

3.1.1 Raw Material Control:

3.1.1.1 Sponge: Melt source shall either produce or procure sponge to a specification approved as in 4.4.2.1.1. Sponge shall be free of contaminants known to cause high- and/or low-density inclusions. Composition shall be determined in accordance with ASTM E120.

3.1.1.2 Master Alloy: Melt source shall procure master alloy to a specification approved as in 4.4.2.1.1. Master alloy shall be free from oxides, nitrides, and other detrimental foreign materials, including materials which could cause high- and/or low-density inclusions. The boron content of the master alloy shall not exceed 0.005% (50 ppm). Methods of analysis shall be as agreed upon by the melting source and master alloy purchaser.

3.1.1.3 Recycling: Previously multiple-melted alloy may be recycled provided such material is clean, free of discoloration, high-density material, and carbides, and is segregated as to alloy grade. No flame-cut material shall be recycled unless all oxides and discolored areas are removed by blasting or by alkaline salt bath scale removal treatment followed, in either case, by acid pickling and rinsing. Turnings which have been cut with carbide tools may be recycled provided they are 100% radiographically inspected and shown to be free of high-density material. No severely split material or rough billet ends containing adhering scale or other extraneous material shall be recycled.

3.1.2 Melting Practice: Grade 1 material shall be double melted under vacuum and Grade 2 material shall be triple melted under vacuum using consumable electrode practice. The critical variables of each melting cycle shall be continuously monitored and recorded.

3.1.2.1 A suitable vacuum during the steady state portion of the first melt is defined as a pressure not higher than 2000 microns of mercury with occasional momentary peaks not higher than 6000 microns of mercury. The pressure shall be maintained by continuous pumping. A suitable vacuum during the steady state portion of subsequent melts is defined as not higher than 1000 microns with occasional momentary excursions to 4000 microns permitted. A momentary peak is defined as a temporary surge of pressure which recovers to the original pressure level in not more than 60 seconds.

3.1.2.2 Welding of primary melt electrodes for either Grade 1 or Grade 2 material and of second melt electrodes for Grade 2 material shall be performed in an inert gas filled chamber or fixture, using plasma arc, electron beam, or gas metal arc (GMA) techniques only; use of gas tungsten arc (GTA) welding is not permitted. Welding of the holding fixture may be performed with an inert gas shielded plasma but such weld shall not be used as recycle material and if this weld joint is melted into the ingot, that portion of the ingot shall be removed. Gas metal arc welding of the holding fixture is permitted outside the chamber provided that melting the ingot into the weld joint is avoided.

3.1.2.3 Preliminary Melting Cycles: Any of the following discrepancies occurring during the first melting cycle for Grade 1 material or during either the first or second melting cycles for Grade 2 material shall disqualify the heat for use as material to which this specification applies.

3.1.2.3.1 Any loss of vacuum exceeding the limits of 3.1.2.1 associated with an air leak.

3.1.2.3.2 Any water leak occurring during the melting cycle as confirmed by chemical analysis after grinding. Minor discoloration due to pinhole water leaks may be ground out. Material shall be considered acceptable only if chemical analysis of the leak area after grinding indicates absence of contamination.

3.1.2.3.3 Any unscheduled furnace disassemblies.

3.1.2.4 Final Melt Cycle: Any of the following melting discrepancies shall disqualify the heat for use as material to which this specification applies.

3.1.2.4.1 Any loss of vacuum exceeding the limits of 3.1.2.1.

3.1.2.4.2 Any water leak into the ingot chamber during the melting period. Minor discoloration due to pin-hole water leaks may be ground out. Material shall be considered acceptable only if chemical analysis of the leak area after grinding indicates absence of contamination.

3.1.2.4.3 Any power interruption lasting longer than 30 sec during the melting cycle.

3.1.2.5 Hot Topping: Ingots shall be hot topped according to an established procedure with defined limits which shall be continuously monitored and recorded. If one or more of the defined limits are exceeded in the final melting cycle, the corresponding portion of the ingot shall not be used. The melting discrepancy restrictions of 3.1.2.4.2 and 3.1.2.4.3 shall apply during hot topping.

3.2 Forging and Extruding Stock: Billet, bar, and slabs for forging and extruding shall be manufactured from ingot produced as in 3.1. Limits shall be established for ingot conversion procedures which will produce stock conforming to the following requirements; these limits shall be continuously monitored and recorded. Deviations from established control factors for ingot conversion procedures of 4.4.2.1.2 shall be reported to the purchaser of the stock and his approval obtained before the stock may be considered acceptable.

3.2.1 Macrostructure and Defects:

3.2.1.1 Visual examination at 1X of transverse sections of forging stock and extruding stock, etched in accordance with AMS 2643 for sufficient time to develop a well-defined macrostructure, shall show no injurious imperfections such as unhealed pipe, cracks, porosity, laps, folds, pitted areas, segregation, and inclusions detrimental to fabrication or to performance of parts. A processing tree-ring structure is permitted provided there is no chemical segregation.

3.2.1.1.1 Macro-Grain Structure: The macro-grain structure shall be equal to or better than the following levels of Table I; visual standards for macro-grain structure are shown in Figs. 1 through 10:

TABLE I

MACRO-GRAIN STRUCTURE STANDARDS
FORGING AND EXTRUDING STOCK

Rounds:

Nominal Diameter, Inches	Nominal Diameter, (Millimeters)	Macro-Grain Structure Level, Ti-6Al-4V	Macro-Grain Structure Level, Other Alloys
Up to 4.5, incl	(Up to 114, incl)	30	30
Over 4.5 to 9.0, incl	(Over 114 to 229, incl)	40	50
Over 9.0 to 14.0, incl	(Over 229 to 356, incl)	50	60
Over 14.0 to 17.0, incl	(Over 356 to 432, incl)	60	70
Over 17.0	(Over 432)	70	70

Squares, Rectangles, Hexagons, Octagons:

Nominal Cross Sectional Area, Square Inches	Nominal Cross Sectional Area, (Square Centimeters)	Macro-Grain Structure Level, Ti-6Al-4V	Macro-Grain Structure Level, Other Alloys
Up to 16, incl	(Up to 103, incl)	30	30
Over 16 to 63, incl	(Over 103 to 406, incl)	40	50
Over 63 to 153, incl	(Over 406 to 987, incl)	50	60
Over 153 to 226, incl	(Over 987 to 1458, incl)	60	70
Over 226	(Over 1458)	70	70

3.2.1.2 When specified by purchaser, the specimens shall be etch-anodize inspected in accordance with AMS 2642 to determine the nature and extent of segregation and other defects.

3.2.1.3 Any macrostructural defects including unhealed pipe, cracks, laps, porosity, folds, pitted areas, segregation, and inclusions which are visible at 1X with 20/20 standard vision at a light intensity of 200 ft-candles (2153 lm/m^2) shall be cause for rejection of the material. Figures 11 through 13 are typical of the type but not the minimum size of such defects which are cause for rejection.

3.2.2 Ultrasonic Inspection: The product of alloys 6Al-4V; 6Al-2Sn-4Zr-2Mo; 6Al-6V-2Sn only shall conform to the following classification requirements, determined in accordance with AMS 2631, using longitudinal wave method. Product size and configuration at which the inspection is performed shall be as agreed upon by purchaser and vendor. Product containing indications exceeding the limits of the applicable classification of 3.2.2.1, 3.2.2.2, or 3.2.2.3 shall not be shipped or subjected to further processing until the indications have been investigated and verified as to type.

3.2.2.1 Rounds:

Nominal Diameter		Ultrasonic Classification
Inches	(Millimeters)	
Up to 4.0, incl	(Up to 102, incl)	AA
Over 4.0 to 9.0, incl	(Over 102 to 229, incl)	A1
Over 9.0 to 14.0, incl	(Over 229 to 356, incl)	A
Over 14.0	(Over 356)	B

3.2.2.2 Other Than Rounds, Except Plate:

Nominal Diameter Between Parallel Sides		Ultrasonic Classification
Inches	(Millimeters)	
Up to 3.0, incl	(Up to 76, incl)	AA
Over 3.0 to 9.0, incl	(Over 76 to 229, incl)	A1
Over 9.0 to 14.0, incl	(Over 229 to 356, incl)	A
Over 14.0 to 18.0, incl	(Over 356 to 457, incl)	B

3.2.2.3 Plate:

Nominal Thickness		Ultrasonic Classification
Inches	(Millimeters)	
0.5 to 4.0, incl	(13 to 102, incl)	A1

3.2.2.4 Product containing evidence of the following conditions found by ultrasonic inspection and identified by metallurgical investigation or by macroetching in accordance with AMS 2643 may be used only if the requirements of 3.2.2.5 and 3.2.2.6 are met: interstitially stabilized alpha structure (Type I), aluminum-rich stabilized alpha structure (Type II), voids, porosity, bursts, end concavity and enfoliations, striated alpha segregates, high density inclusions, shallow surface laps, and pipe.

3.2.2.5 Areas containing ultrasonic indications shall be removed and verified as to type. End faces of removed sections shall be etched and shall be free of defects; if end faces reveal defects, the product shall be further cropped as required. If only evidence of grain size variation is found after etching, no further cropping will be required.

3.2.2.6 Any indication below the maximum acceptance levels of 3.2.2.1, 3.2.2.2, or 3.2.2.3 but significantly higher than the noise level, indicative of either Type I or Type II stabilized alpha, voids, porosity, bursts, striated alpha segregates, high density inclusions, or pipe, shall be removed and investigated.

3.2.2.7 All areas containing surface defects shall be locally etched after removal of the defects to ensure that the defects have been completely removed.

3.3 Forgings: Shall be produced from forging stock conforming to 3.2.

3.3.1 Preproduction Forgings:

3.3.1.1 The forging vendor shall produce preproduction forgings and shall heat treat these forgings as specified by the purchaser. A representative forging or section thereof shall be tested to determine conformance to all applicable technical requirements of the material specification and this specification and supplementary requirements of the drawing and purchase order. A second forging or the balance of the vendor test forging shall be furnished to the purchaser for confirmatory tests. The preproduction forgings may be produced as part of the initial production run.

3.3.1.2 One or more sections taken from designated areas of the test forgings shall be suitably prepared and etched to reveal the cross sectional structure, including grain flow if discernible, developed in the forgings. The section or sections shall also be used for general macrostructure examination and hardness surveys. Photographs of the section or sections shall be furnished to the purchaser.

3.3.1.3 A resume of the control factors of processing (See 4.4.2.1.3) used to produce preproduction forgings shall be submitted with the results of tests conducted on such forgings. Alternatively, the resume need not be submitted with the test results but shall be prepared and kept on file for inspection by the purchaser at any time.

3.3.2 Production Forgings:

3.3.2.1 Production forgings shall be produced using the same basic operations and practices, and the same tolerances where applicable, as used on the approved (See 4.4) preproduction forgings.

3.3.2.2 No production forgings shall be shipped prior to receipt from purchaser of written approval of the preproduction forgings.

3.3.3 Forging Acceptance Standards: Preproduction and production forgings shall conform to the following requirements:

3.3.3.1 Macrostructure: Visual examination of representative forgings etched in accordance with AMS 2643 shall show a uniform structure of fine or medium grain size as defined in Fig. 14 and 15 and shall show no injurious imperfections such as pipe, cracks, porosity, laps, folds, pitted areas, segregation, and inclusions detrimental to fabrication or to performance of parts. (Examples of defects are shown in Figs. 11, 12, and 13). If the grain size is obscured by flow lines, as indicated in Fig. 16, the structure shall be acceptable. Figure 17 is defined as unacceptable coarse grains in section sizes under 5 in. (127 mm), and Fig. 18 is defined as unacceptable coarse grains in section sizes under 9 in. (229 mm).

3.3.3.2 Etch-Anodize Inspection: If the macrostructural examination of 3.3.3.1 shows evidence of segregation and, when specified by purchaser, whether or not there is evidence of segregation, specimens cut from forgings shall be etch-anodize inspected in accordance with AMS 2642 to determine the nature and extent of segregation and other defects. Visual evidence of segregation at 1X with standard vision at a light intensity of 200 ft candles (2153 lm/m^2) may be cause for rejection. Figure 19 shows typical example of segregation defects.

3.3.3.3 Microstructure: Specimens cut from forgings, polished and etched as in AMS 2642 or by other suitable polishing and etching techniques, shall have an acceptable microstructure as determined by comparison with the standards shown in Figs. 20, 21, and 22.

3.3.3.4 Ultrasonic Inspection: Each forging shall be inspected in accordance with AMS 2631 and shall meet the requirements of 3.2.2 as applicable to the size of stock from which the forging was made.

3.3.3.5 Etch Inspection: Each forging shall be etched and inspected to reveal surface imperfections in accordance with AMS 2643 or AMS 2642 as agreed upon by purchaser and vendor, and, when specified by purchaser, shall be machined prior to etching to reveal segregation and inclusions. Examples of defects are shown in Figs. 13 and 19.

3.4 Finished Mill Products:

3.4.1 Bar and Plate: Shall be manufactured from ingot which meets the requirements of 3.1. The finished bar and plate shall meet the requirements of 3.2 and 3.3.3.3.

3.4.2 Extrusions: Shall be produced from extruding stock conforming to 3.2. Visual examination of a slice from the back end of each extrusion, etched in accordance with AMS 2643, shall show a uniform structure and no injurious imperfections such as pipe, cracks, porosity, laps, folds, pitted areas, segregation, and inclusions detrimental to performance of the product.

3.5 Quality Requirements: In the event that more than three distinct and separate confirmed areas of segregation, inclusions, voids or combination thereof per ingot are found, or more than one per 1500 lb (681 kg) of ingot product are found, whichever is less, the entire ingot product shall be rejected. Conformance to this requirement shall apply only to products over 4.5 in. (114 mm) in thickness or diameter.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection: The vendor of the product shall supply all samples and shall be responsible for performing all required tests. Results of such tests shall be reported to the purchaser as required by 4.6. Purchaser reserves the right to perform such confirmatory testing as he deems necessary to assure that the product conforms to the requirements of this specification.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: Tests to determine conformance to the following requirements are classified as acceptance or routine control tests:

4.2.1.1 Elemental Additions: Composition requirements of the respective procurement specifications.

4.2.1.2 Sponge, Master Alloy, and Recycle Material: Visual and X-ray inspections and composition requirements of the respective procurement specifications.

4.2.1.3 Stock for Forging or Extruding: Composition, macrostructure, and ultrasonic inspection.

4.2.1.4 Forgings, Bar, and Plate: Ultrasonic, microstructural, and etch inspections and the acceptance tests of the material specification.

4.2.1.5 Extrusions: Macrostructure examination and the acceptance tests of the material specification.

4.2.2 Qualification Tests: Tests to determine conformance to the following requirements are classified as qualification or periodic control tests.

4.2.2.1 Sponge, Master Alloy, and Elemental Additions: Trace element determination.

4.2.2.2 Forgings, Bar, and Plate: Macrostructure.

4.3 Sampling: Shall be in accordance with the following; when sampling is on a lot basis, a lot shall be as defined in 8.1 for each product.

4.3.1 Composition:

4.3.1.1 Sponge: Each lot shall be sampled in accordance with ASTM B299.

4.3.1.2 Master Alloy: Each lot shall be sampled at a frequency sufficient to assure compliance with the procurement specification.

4.3.1.3 Forging and Extruding Stock, Forgings, Extrusions, Bars, and Plate: At least one sample from each heat except that for hydrogen determinations one sample from each lot.

4.3.2 Macrostructure:

4.3.2.1 Forging Stock: Transverse slices from at least the top of the top billet, bar, or slab and the bottom of the bottom billet, bar, or slab and one intermediate section shall be taken from approximately the middle of the ingot. For macro-grain structure, one slice from the top of each billet and bottom of the bottom billet shall be taken. If only a portion of the heat is used, a slice shall be taken from each end of the portion.

4.3.2.2 Forgings: At least one preproduction forging shall be sectioned so as best to reveal grain flow and general macrostructure. The specific areas to be examined shall be as agreed upon by purchaser and vendor. Production forgings shall be sectioned in the same manner at a frequency agreed upon by purchaser and vendor.

4.3.2.3 Extrusions: Transverse slice from the back end of each extrusion.

4.3.2.4 Bar and Plate: As agreed upon by purchaser and vendor.

4.3.3 Etch Inspection: Each forging shall be etched to reveal surface defects and, when specified by the purchaser, the forging shall be machined and etched to reveal subsurface defects and segregation.

4.3.4 Ultrasonic Inspection:

4.3.4.1 Forging and Extruding Stock, Bar, and Plate: Each billet, bar, and plate.

4.3.4.2 Forgings and Extrusions: As specified by purchaser.

4.4 Approval:

4.4.1 Preproduction forgings and the forging procedure shall be approved by purchaser before forgings for production use are supplied. Approval of preproduction forgings shall in no way relieve the forging vendor of responsibility for continued conformance to all purchase order requirements.

4.4.2 The respective vendors shall establish for ingot, forging and extruding stock, bar, plate, and forgings and extrusions of each part number or configuration, the control factors of processing which will yield products meeting the respective requirements of this specification and the material specification. These shall constitute the approved manufacturing procedures for each product and shall be used for subsequent production of the product. If necessary to make any change in control factors of processing which could affect quality or properties of the product, vendor shall submit for reapproval a detailed statement of the revised operations and, when requested, sample product. No production products incorporating the revised operations shall be shipped prior to receipt of reapproval.

4.4.2.1 Control factors for producing the product include, but are not limited to, the following for the respective forms:

4.4.2.1.1 Ingot:

Sources of sponge, master alloy, elemental additions, and recycle material
Specifications and inspection procedures for sponge and master alloy
Procedures for use of recycle alloy
Arc voltage and current
Melting chamber pressure
Ingot cooling procedure
Hot topping practice
Ingot quality analysis procedure
Preparation of ingot for remelting after each preliminary melting cycle
Electrode fabrication procedure

4.4.2.1.2 Forging and Extrusion Stock:

Source and size of ingot
Conversion source if not the ingot source
Preparation of ingot for conversion
Ingot heating procedure
Cogging and rolling procedures
Inspection procedures

4.4.2.1.3 Forgings:

Source of stock
Nominal size (cross sectional area) and shape of forging stock
Type of processing equipment (e.g., press, hammer, ring roll, mill, etc)
Sequence or number of operations change in which would result in a different cross sectional structure or in different working of the metal
Protective atmosphere and/or coatings, if used
Thermal cycling, including heating for working and specified heat treatment of the product
Cleaning operations (e.g., chemical descaling, blasting, etc)
Inspection procedures

4.4.2.1.4 Any of the above control factors of processing considered proprietary by the vendor may be assigned a code designation. Each variation in such factors shall be assigned a modified code designation.

4.5 Records:

4.5.1 Maintenance of Facilities: Each vendor shall keep records demonstrating that the facilities used to produce, control, measure, and test the respective products during manufacture and inspection are properly maintained and are checked at stated intervals against acceptable standards for accuracy.

4.5.2 Process Sheets: Each vendor shall prepare and maintain documented instructions defining the processing methods and routing in the manufacturing cycle for producing the respective products.

4.5.3 Traceability: Each vendor shall maintain records to provide traceability of the forging back to a particular billet or slab over 16 sq in. (103 cm^2) and of each billet and slab over 16 sq in. (103 cm^2) to its location and orientation in the final remelt ingot. The disposition of all stock shall be maintained by the vendor (e.g., scrapped for cause, shipped, still in ingot form, etc). A similar degree of traceability may be requested by the purchaser for other product forms. Records shall be maintained for at least seven years.

4.6 Reports: Vendor shall furnish with each shipment reports of the results of product tests to determine conformance to the technical requirements of this specification. These data shall be included in the report required by the material specification.

4.7 Resampling and Retesting: If any specimen of any product used in the above tests fails to meet the specified requirements, disposition of the product may be based on the results of additional testing as specified below. Except where retesting results in discard of nonconforming material, failure of any retest specimen to meet the specified requirements shall be cause for rejection of the material represented and no additional testing shall be permitted. Resampling and retesting of bars, plate, and extrusions shall be in accordance with requirements of the applicable material specification.

4.7.1 If segregation, laps, folds, cracks, pitted areas, inclusions, or voids are found in macrostructural examination of forging and extruding stock, two adjacent slices, one adjacent to each face of the original slice shall be cut and examined. This procedure may be repeated until it is assured that the defective area has been removed.

4.7.2 If acceptable limits of macrostructure are exceeded, further working of forging and extruding stock to produce a smaller size with acceptable macrostructure is permitted.

4.7.3 If ultrasonic indications greater than the limits permitted for the respective class are found, the areas containing such indications shall be removed and examined. If adequate analysis can be made from observation of the ultrasonic indications to identify the cause of the indication, no further investigation is required. If the nature or extent of the indications cannot be adequately analyzed by examination, the removed portion shall be further sectioned to complete the analysis. The product faces adjacent to the indications shall be macroetched and examined. If the ultrasonic indications are determined to be isolated and caused by, or associated with, segregation, voids, or inclusions, the remainder of the affected billet, bar, or slab may be used. However, if etching of the adjacent cut faces of the product reveals additional evidence of segregation, voids, or inclusions, further cutting, etching, and examination as in 4.7.1 shall be conducted until it is assured that the defective area has been removed.

5. PREPARATION FOR DELIVERY:

5.1 Identification: All product forms ordered to and meeting this specification shall be identified with AMS 2380 and the following:

5.1.1 Ingot and Extruding Stock: Shall be identified as agreed upon by purchaser and vendor.

5.1.2 Forging Stock, Forgings, Extrusions, Bar, Plate, and Slab: Shall be identified in accordance with requirements of the applicable material specification.

5.2 Packaging: The product shall be prepared for shipment in accordance with commercial practice to assure carrier acceptance and safe transportation to the point of delivery. Packaging shall conform to carrier rules and regulations applicable to the mode of transportation.

6. ACKNOWLEDGMENT: A vendor shall mention this specification number in all quotations and when acknowledging purchase orders.

7. REJECTIONS: Material not conforming to this specification or to authorized modifications will be subject to rejection.

8. NOTES:

8.1 Definition of "Lot":

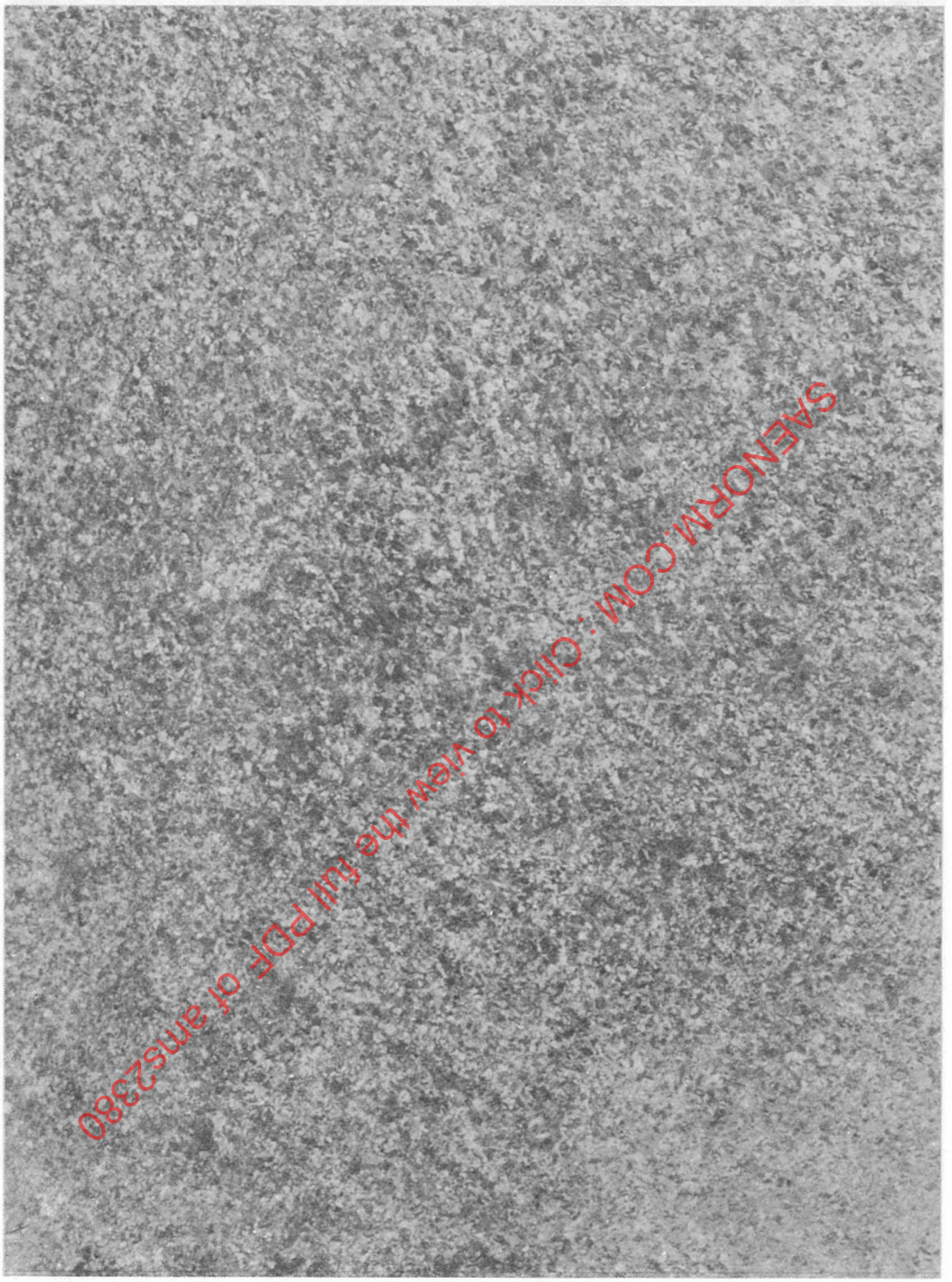
8.1.1 Sponge and Master Alloy: A lot shall be all material produced in one time period by a single source as defined by the producer's specification and maintained, sampled, tested, and inspected as a common unit.

8.1.2 Forging and Extruding Stock: A lot shall be all material of the same nominal size from the same heat processed in accordance with the same approved manufacturing procedures.

8.1.3 Forgings, Extrusions, Bar, and Plate: A lot shall be all material of the same part number or configuration from the same heat and processed in accordance with the same approved manufacturing and heat treatment procedures.

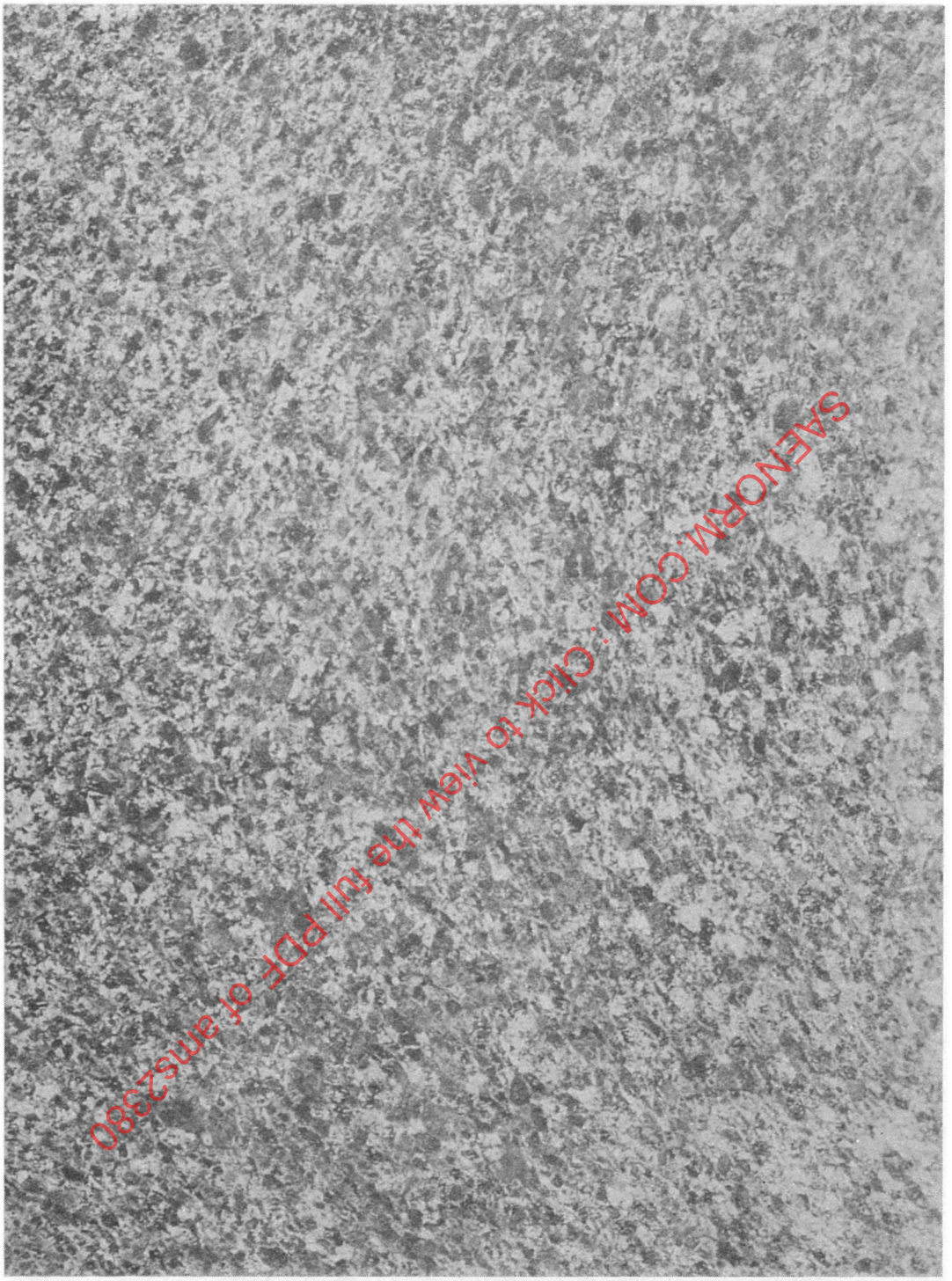
Level 10 Titanium Billet Macrostructure at 1X

FIGURE 1



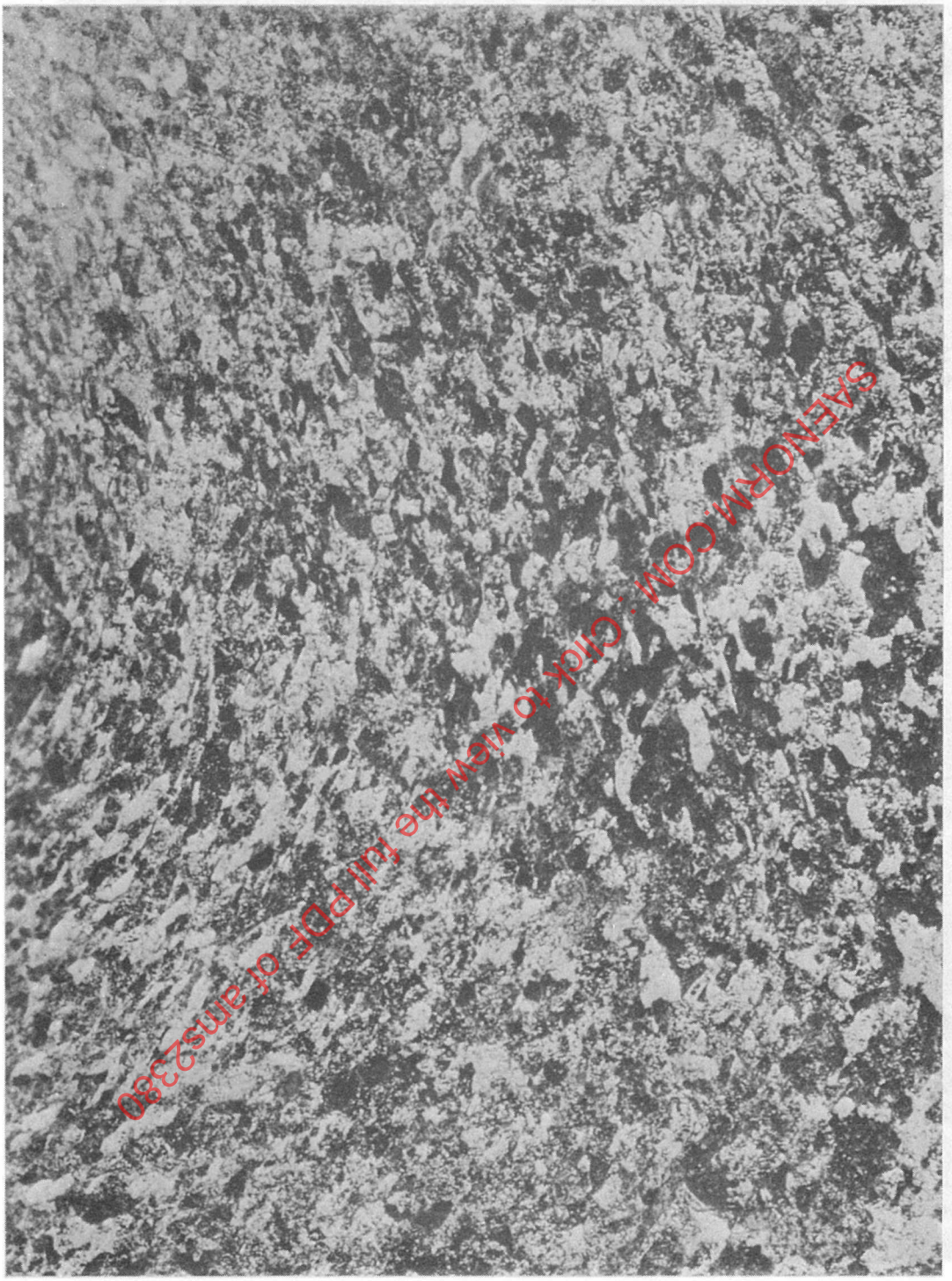
Level 20 Titanium Billet Macrostructure at 1X

FIGURE 2



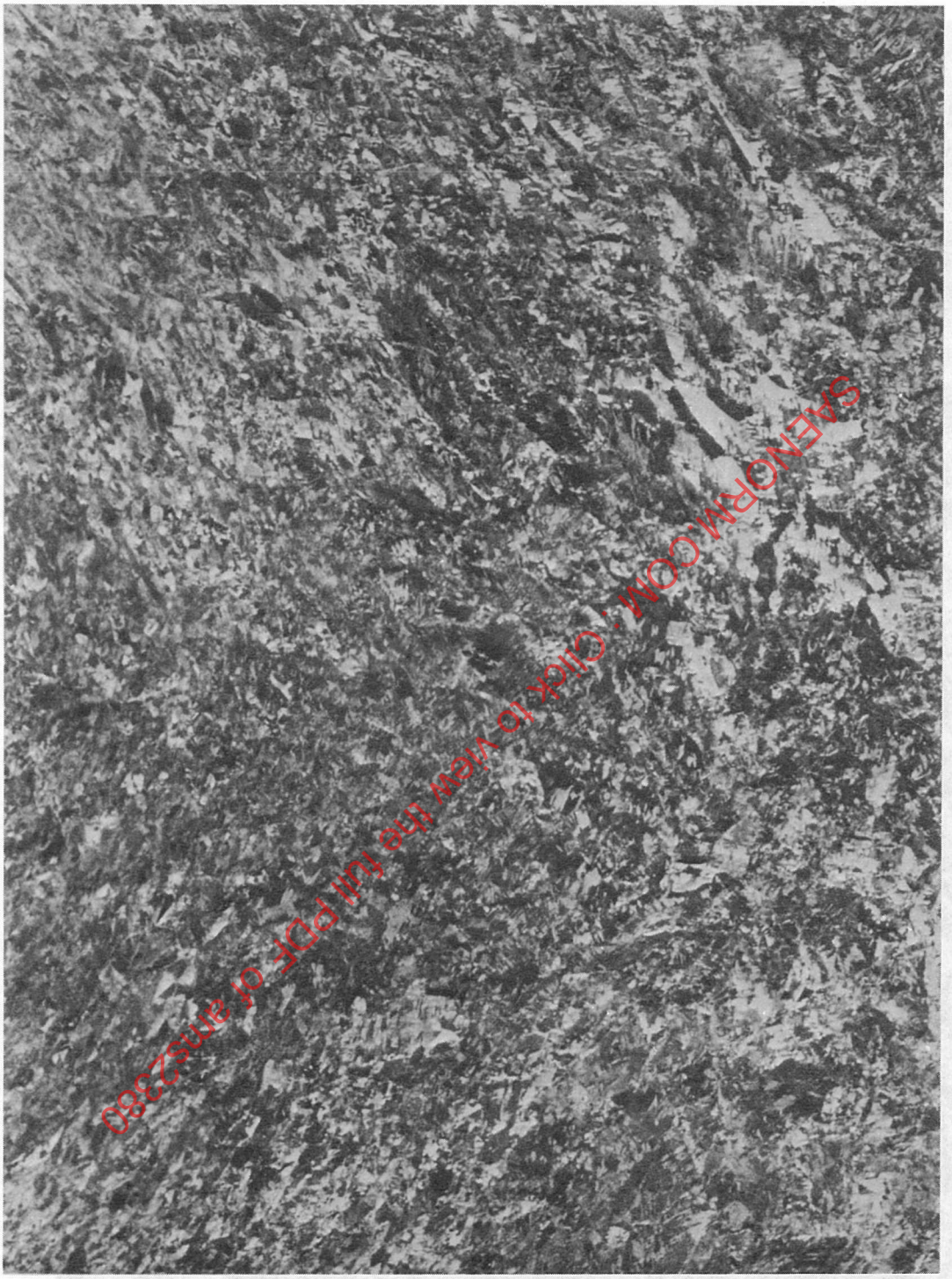
Level 30 Titanium Billet Macrostructure at 1X

FIGURE 3



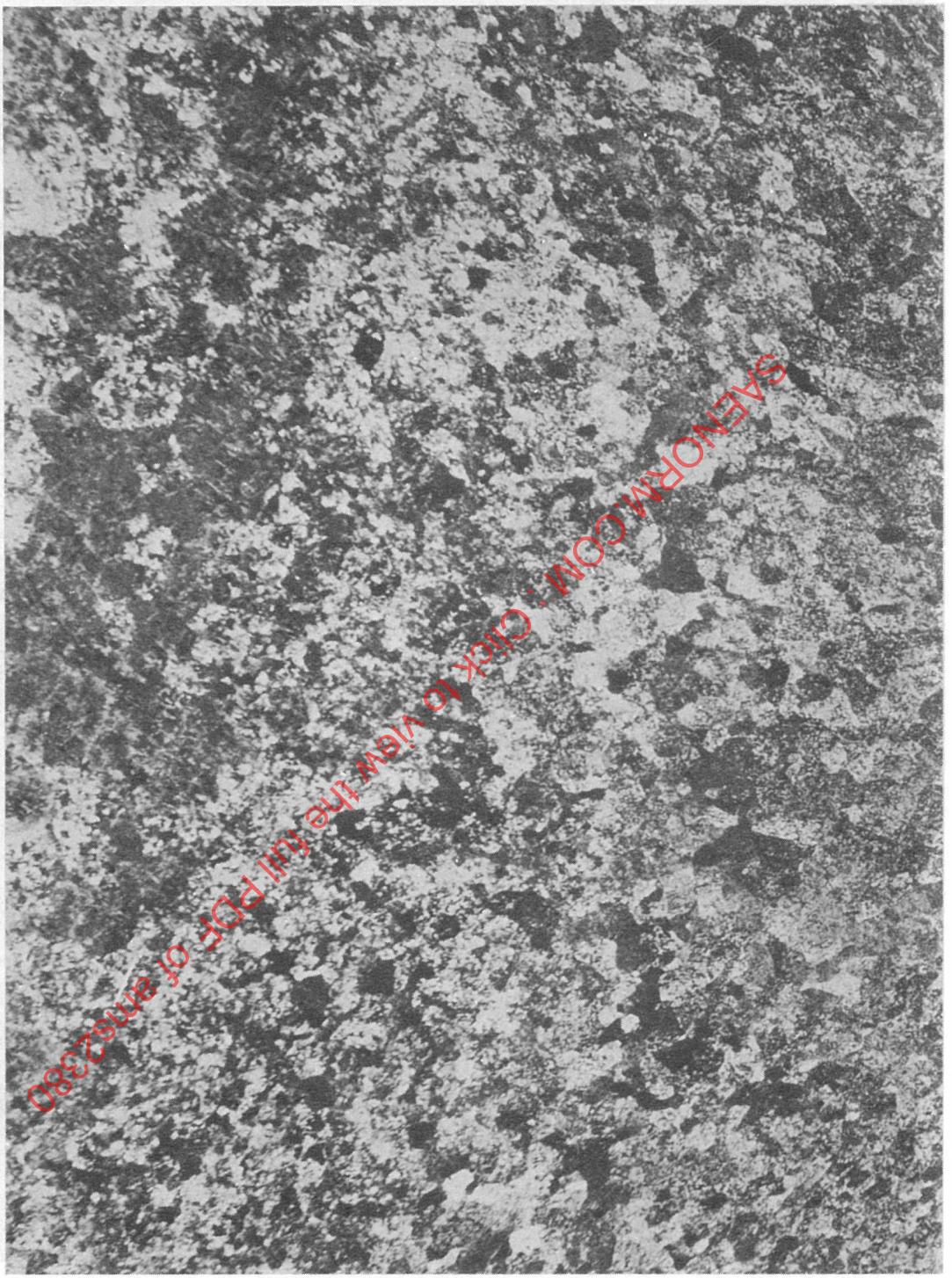
Level 40 Titanium Billet Macrostructure at 1X

FIGURE 4



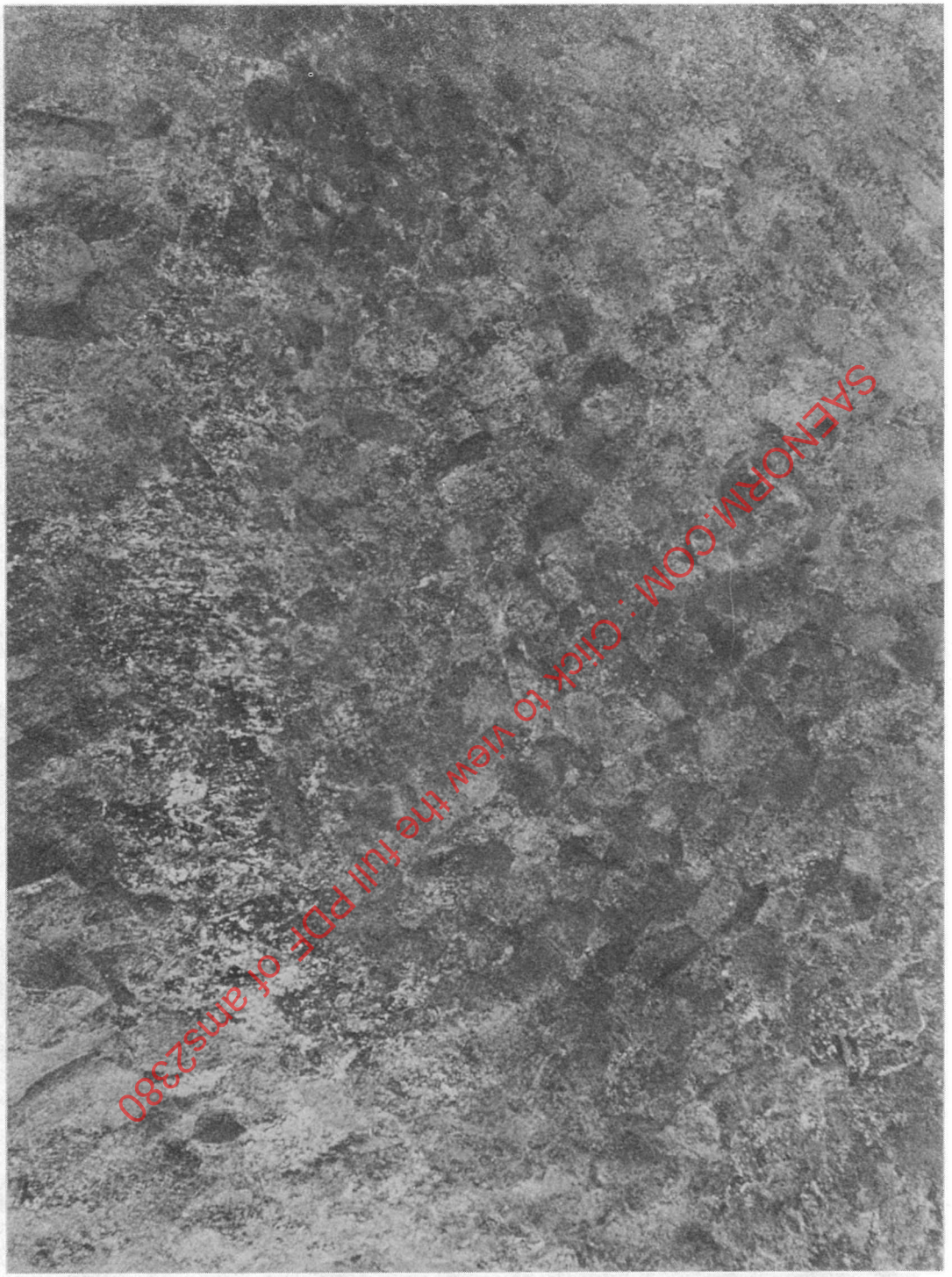
Level 50 Titanium Billet Macrostructure at 1X

FIGURE 5



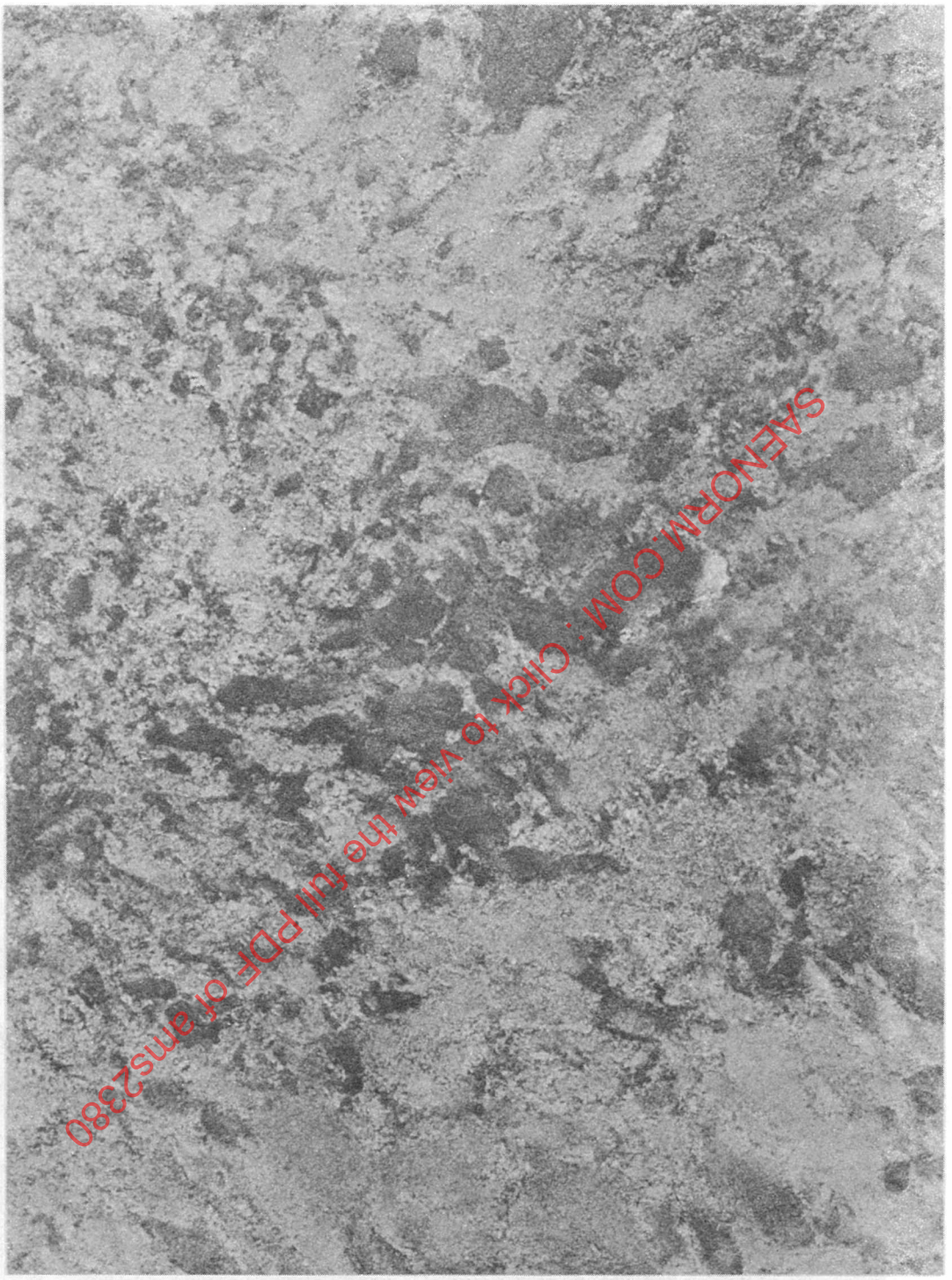
Level 60 Titanium Billet Macrostructure at 1X

FIGURE 6



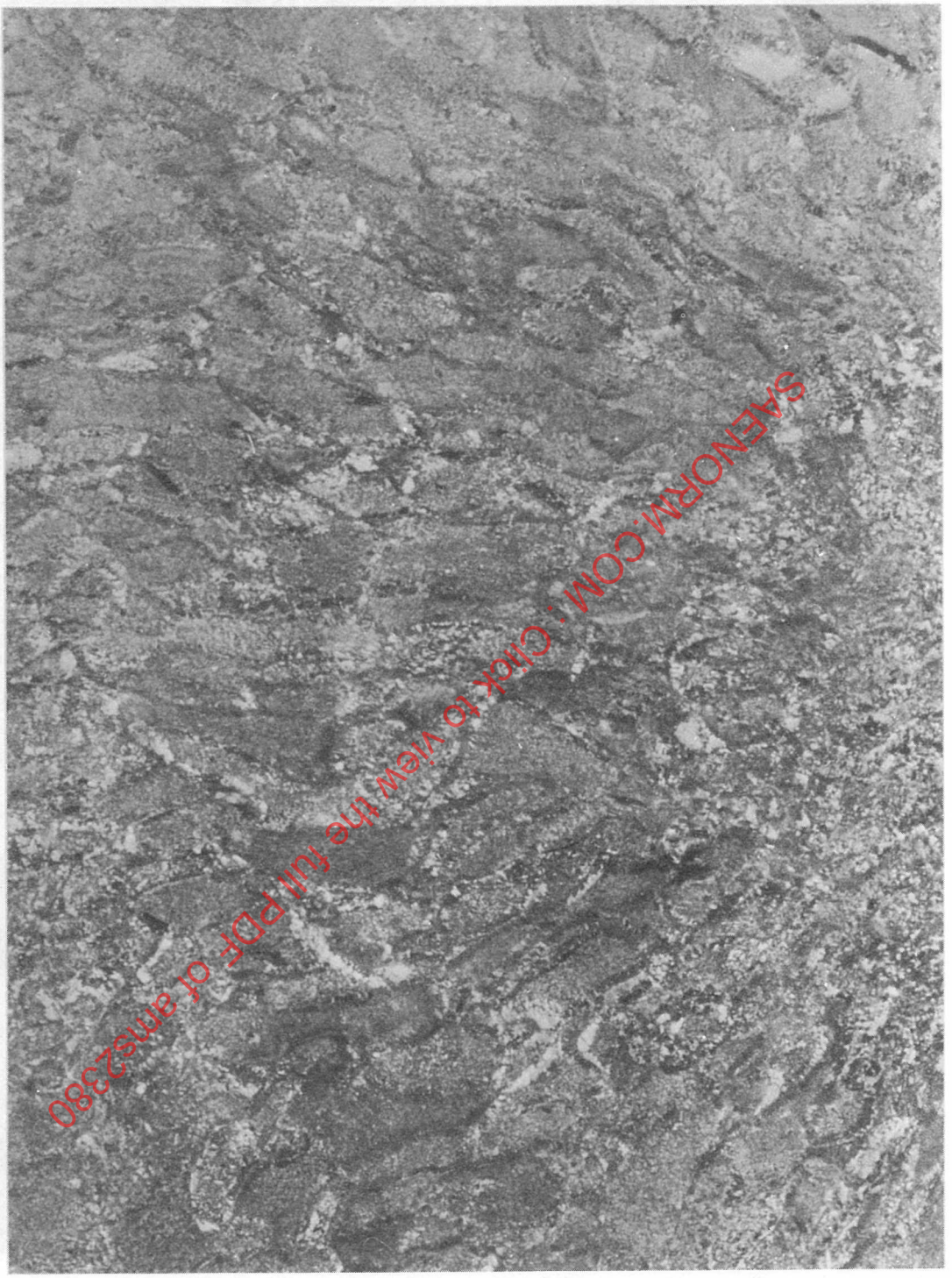
Level 70 Titanium Billet Macrostructure at 1X

FIGURE 7



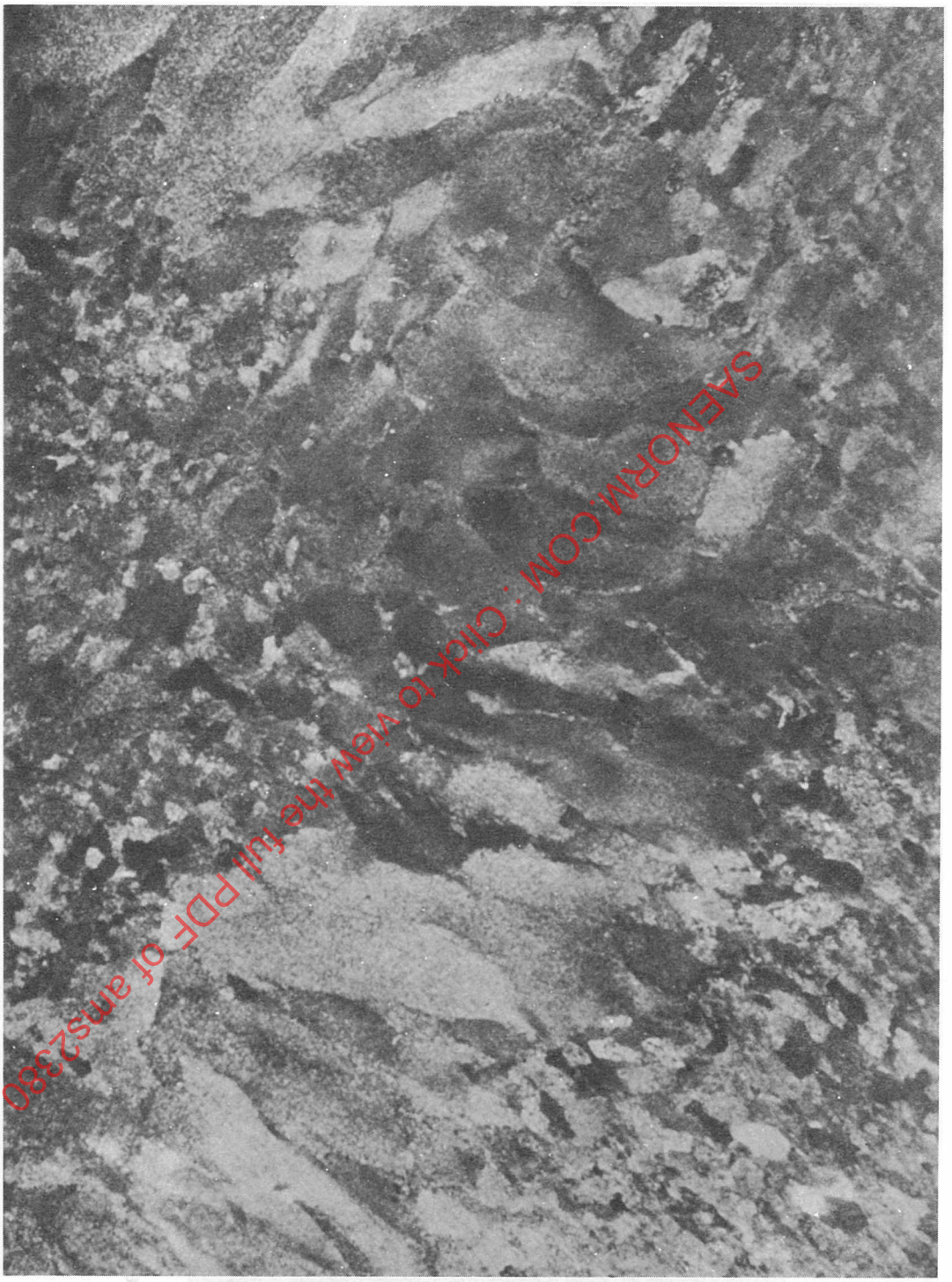
Level 80 Titanium Billet Macrostructure at 1X

FIGURE 8



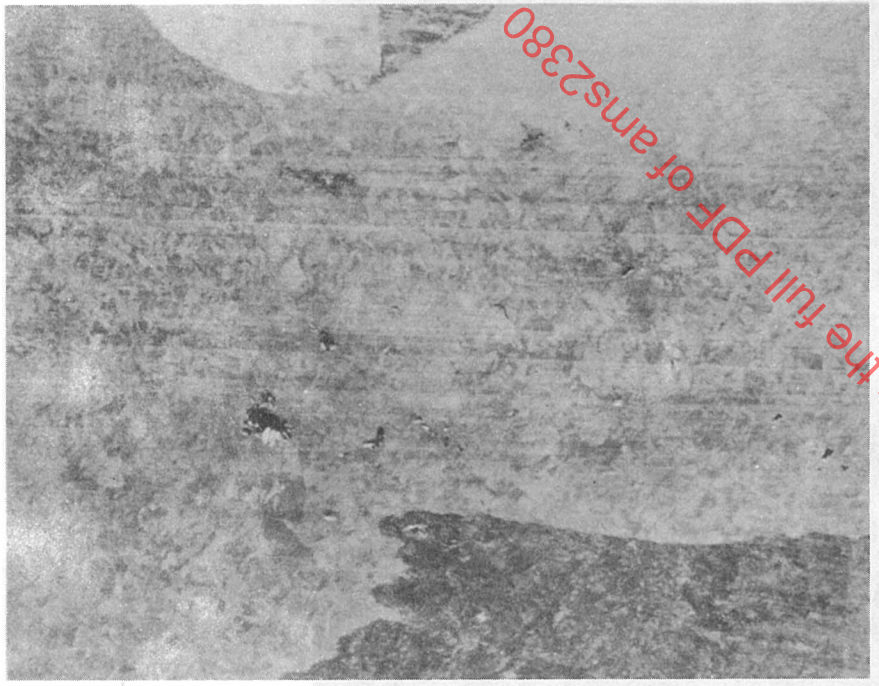
Level 90 Titanium Billet Macrostructure at 1X

FIGURE 9



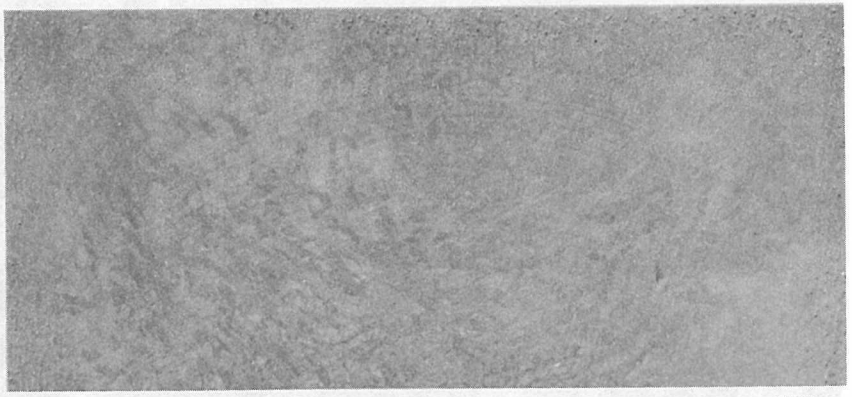
Level 100 Titanium Billet Macrostructure at 1X

FIGURE 10



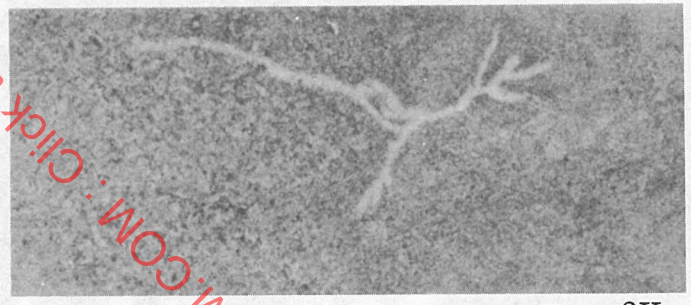
1X

Unacceptable Secondary Pipe
FIGURE 11



1X

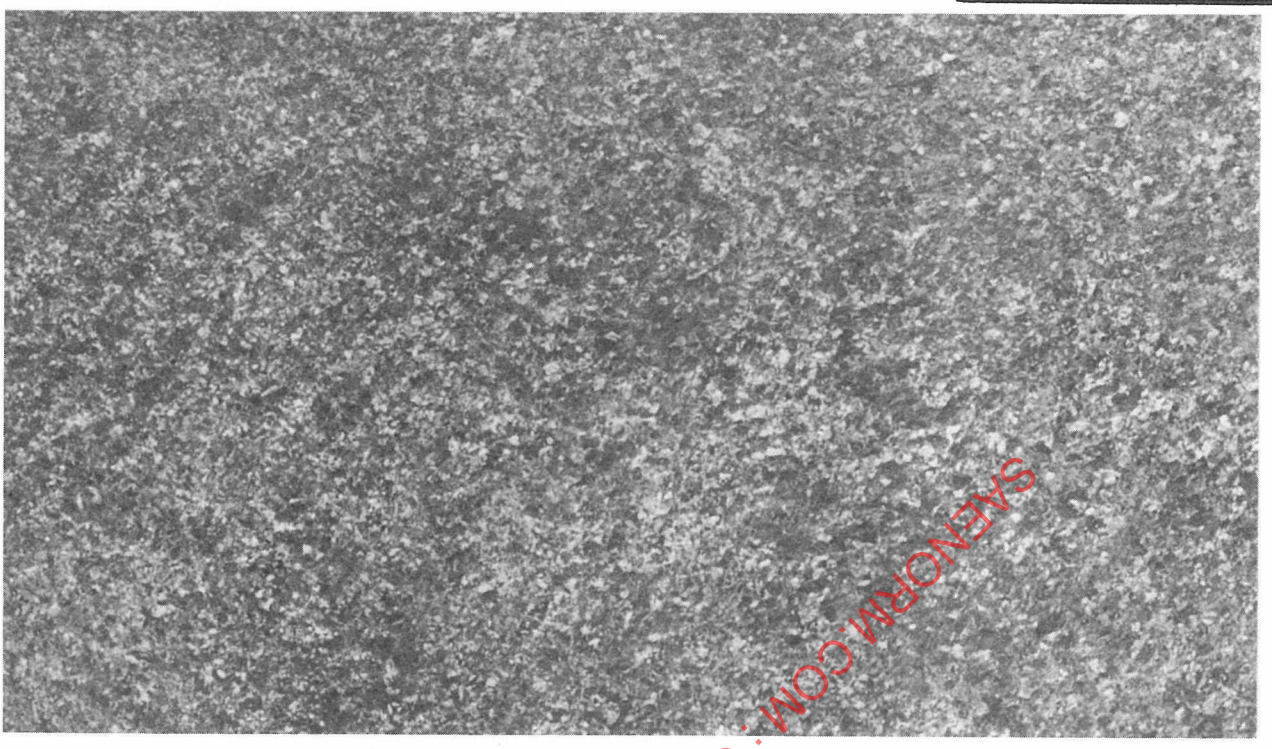
Unacceptable Porosity
FIGURE 12



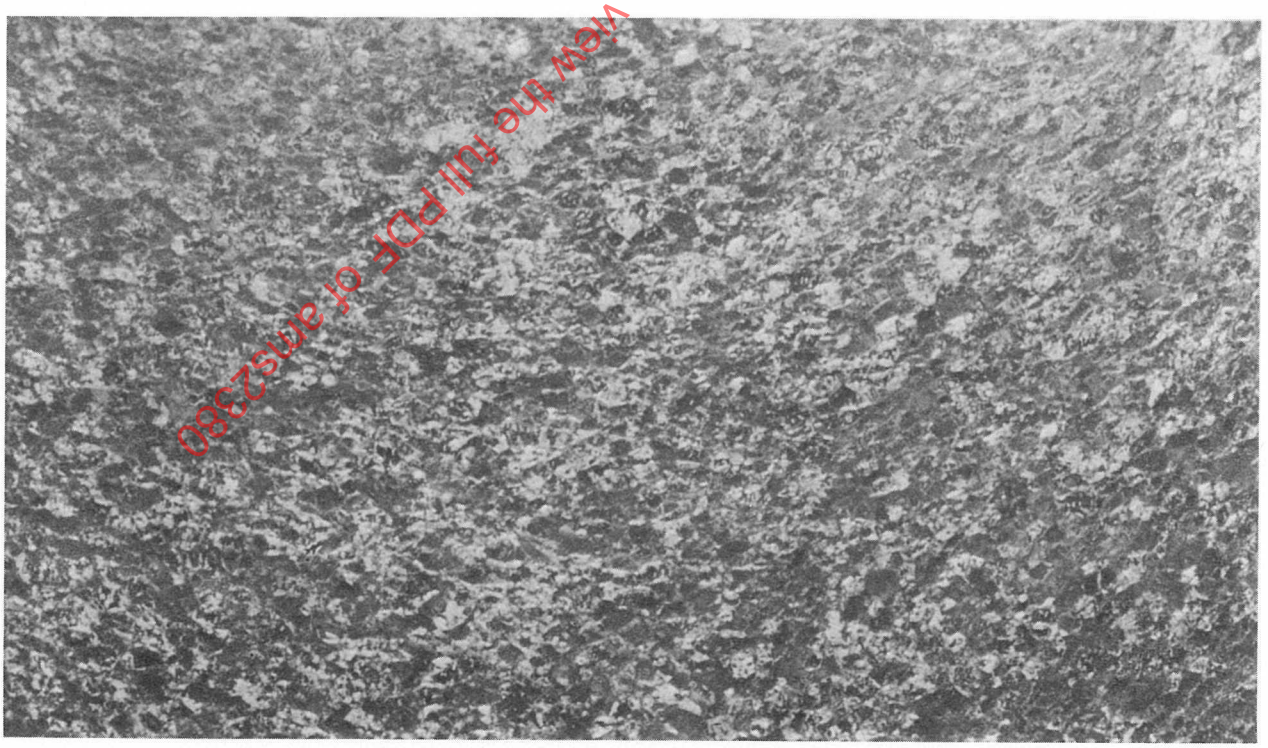
2X

Conditionally Unacceptable Alpha Segregation (Final Acceptance Based Upon Acceptable Microstructure)
FIGURE 13

TYPICAL TYPES OF MACROSTRUCTURAL DEFECTS



Acceptable, Fine Macro-grain, Uniform Macrostructure
FIGURE 14



Acceptable, Medium Macro-grain, Uniform Macrostructure
FIGURE 15

MACROSTRUCTURE ACCEPTANCE STANDARDS FOR FORGINGS AT 1X