TB15 / Ti6554 | ENGLISH TRANSLATION

Process for preparing titanium-alloy bar blanks by combining extrusion breakdown and pulsed-current heat treatment

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Complete technical reference translation

This English edition translates the abstract, all eight claims, all 51 numbered description paragraphs, both examples, all tables, five drawings and bibliographic information. Ti6554 is the alloy in Example 1; Example 2 concerns Ti55531. Flow diagrams are redrawn with English labels; micrographs are reproduced from the source with translated annotations. This is an uncertified reference translation; the original Chinese publication controls. Patent claims of benefits are historical disclosure statements, not independent verification, a purchase specification, a material certificate or a TiHubs performance guarantee.

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Abstract

The invention relates to a process for preparing titanium-alloy bar blanks by combining extrusion breakdown and pulsed-current heat treatment. A titanium-alloy ingot undergoes extrusion breakdown A at temperature T1. Pulsed current is applied after extrusion breakdown A, and solution treatment A is carried out at T2. After solution treatment A, cooling treatment A is performed, followed by extrusion breakdown B at T3. After extrusion breakdown B, the material is cooled to T4, pulsed current is applied, and solution treatment B is conducted at T5. After solution treatment B, cooling treatment B is performed, pulsed current is applied again, and the material is heated to T6 for solution treatment C and air-cooled to room temperature. Finally, pulsed current heats the material to T7 for ageing, producing a titanium-alloy bar blank. Combining extrusion breakdown with pulsed-current heat treatment produces homogeneous, high-strength titanium-alloy bars, improves microstructural uniformity and mechanical properties, and addresses the performance requirements of aerospace fasteners.

Cited prior art

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Translation notes

Source inconsistencies are retained: the general extrusion-ratio range is 4-8, whereas the B-extrusion table gives 9; the text gives differing holding/cooling details. The source specifies frequency without a unit and Table 4 omits the current-density unit. The heating-time row spanning treatment columns has been repeated in each column for readability. T_beta denotes the phase-transformation temperature. Source mentions of asbestos and chemical etchants are translated as historical descriptions, not operating recommendations.

Claims

1. A process for preparing titanium-alloy bar blanks by combining extrusion breakdown and pulsed-current heat treatment, characterized by the following operations: perform extrusion breakdown A on a titanium-alloy ingot at T1; apply pulsed current after extrusion breakdown A and perform solution treatment A at T2. After solution treatment A, first perform cooling treatment A, and then perform extrusion breakdown B at T3. After extrusion breakdown B, cool to T4, apply pulsed current, and perform solution treatment B at T5. After solution treatment B, first perform cooling treatment B, then apply pulsed current and heat to T6 for solution treatment C; air-cool to room temperature. Apply pulsed current again to heat to T7 for ageing. The titanium-alloy bar blank is obtained after ageing. T2 lies between T_beta + 30 deg C and T_beta + 60 deg C; T5 lies between T_beta + 30 deg C and T_beta + 60 deg C, where T_beta is the phase-transformation temperature of the titanium alloy. T1 = 1050-1150 deg C; T3 = T_beta + 50 deg C to T_beta + 150 deg C; T4 is at most 300 deg C; T6 = T_beta - 100 deg C to T_beta - 10 deg C; and T7 = 350-450 deg C.

2. The process according to claim 1, wherein the titanium-alloy ingot is obtained by melting in a vacuum consumable-electrode arc furnace.

3. The process according to claim 2, wherein the titanium-alloy ingot is obtained by three successive melts in a vacuum consumable-electrode arc furnace. After melting, the ingot is cooled in a water-cooled copper crucible. The cooling-water inlet temperature is controlled within 25-28 deg C and the outlet temperature within 28-31 deg C. The water-flow rate is adjusted so that the difference between outlet and inlet temperatures is less than 3 deg C. The cooling time is t1, with t1 = k1 D, where k1 is the cooling coefficient and D is the ingot diameter. After cooling, the ingot is removed from the water-cooled copper crucible, wrapped in asbestos or placed in an electric furnace at a temperature not exceeding 400 deg C, and furnace-cooled to room temperature.

4. The process according to claim 1, wherein, during extrusion breakdown A, the extrusion die is preheated to 300 deg C, the extrusion ratio is controlled within 4-8, the extrusion time is less than 8 s, and the extrusion-exit temperature is not lower than T_beta + 40 deg C. After extrusion, the billet is removed from the equipment and air-cooled to room temperature.

5. The process according to claim 4, wherein the titanium-alloy ingot is held at temperature before extrusion breakdown A and B. The holding time is t2, with t2 = k2 D, where k2 is the holding coefficient and D is the ingot diameter.

6. The process according to claim 3, wherein the process parameters for preparing the titanium-alloy ingot by three vacuum consumable-electrode arc melts are controlled as shown in the claim 6 table below.

Process parameter	First melt	Second melt	Third melt
Vacuum before melting (Pa)	<= 1.33 x 10^-2	<= 1.33 x 10^-2	<= 1.33 x 10^-2
Arc-starting current (kA)	1	2.4	2.8
Arc-stabilizing current (A)	1.5	1.5	1.5
Melting current (kA)	1.0-1.2	2.0-2.7	3.0-3.5
Melting voltage (V)	20-25	22-28	22-28
Vacuum during melting (Pa)	<= 6.67 x 10^-1	<= 6.67 x 10^-1	<= 6.67 x 10^-1
Inlet-water temperature (deg C)	<= 25	<= 25	<= 25
Outlet-water temperature (deg C)	<= 30	<= 30	<= 30
Cooling time (min)	>= 20	>= 50	>= 90

7. The process according to claim 4, wherein the process parameters for extrusion breakdown A and B are controlled as shown in the claim 7 table below.

Parameter	Extrusion breakdown A	Extrusion breakdown B
Initial diameter (mm)	170	60
Diameter after extrusion (mm)	60	20
Extrusion ratio	8	9
Heating temperature (deg C)	1130	950
Holding time (h)	2.3	1.5
Furnace-exit temperature (deg C)	1100	920
Material-transfer time (s)	51.36	44.10
Container-entry temperature (deg C)	1000	880
Extrusion-exit temperature (deg C)	935	840
Extrusion time (s)	4	4.5
Extrusion force (tonnes)	1800	1800

8. The process according to claim 4, wherein the process parameters for solution treatments A, B and C and ageing are controlled as shown in the claim 8 table below.

Parameter	Solution A	Solution B	Solution C	Ageing
Current density (A/mm^2)	2.37-2.51	2.37-2.51	2.21-2.42	1.67-1.88
Duty cycle	0.5	0.5	0.5	0.5
Frequency	1	1	1	1
Heating time (s)	600	600	600	600
Holding time (s)	3600	2400	2400	28800

Description

Technical field

[0001] The invention relates to the preparation of titanium-alloy materials, specifically a process for preparing titanium-alloy bar blanks by combining extrusion breakdown with pulsed-current heat treatment.

Background

[0002] As high-end components, titanium-alloy fasteners play an irreplaceable role at connections in thermal-control and structural systems of aircraft, satellites, rockets and other flight vehicles. The conventional Chinese route for titanium-alloy fastener bar blanks is vacuum consumable-electrode melting, open-die forging breakdown, forging or rolling, machining, and heat treatment, as shown in Figure 1. This established route has a complex, lengthy process and unstable product quality, especially poor microstructural uniformity in bar blanks. Examples include different grain sizes, uneven phase-volume-fraction distributions and different textures between the core and edge regions, as shown in Figure 2. These shortcomings seriously reduce mechanical properties and prevent the bars from meeting aerospace requirements. They have constrained quality improvements in domestically produced titanium-alloy bars and pose a significant technical challenge to research institutes and manufacturers.

Summary of the invention

[0003] To solve the above problems, the invention provides a process for preparing titanium-alloy bar blanks by combining extrusion breakdown and pulsed-current heat treatment.

[0004] The technical solution adopted by the invention is as follows.

[0005] A process for preparing titanium-alloy bar blanks by combining extrusion breakdown and pulsed-current heat treatment comprises the following operations.

[0006] Perform extrusion breakdown A on a titanium-alloy ingot at T1. Apply pulsed current after extrusion breakdown A and carry out solution treatment A at T2. After solution treatment A, first carry out cooling treatment A and then extrusion breakdown B at T3. After extrusion breakdown B, cool to T4, apply pulsed current, and perform solution treatment B at T5, followed by air cooling to room temperature. Then apply pulsed current, heat to T6 for solution treatment C, air-cool to room temperature, and continue pulsed-current heating to T7 for ageing. The titanium-alloy bar blank is obtained after ageing.

[0007] A further embodiment specifies the following temperatures. T2 lies between T_beta + 30 deg C and T_beta + 60 deg C; T5 lies between T_beta + 30 deg C and T_beta + 60 deg C, where T_beta is the phase-transformation temperature of the titanium alloy. T1 = 1050-1150 deg C; T3 = T_beta + 50 deg C to T_beta + 150 deg C; T4 is at most 300 deg C; T6 = T_beta - 100 deg C to T_beta - 10 deg C; and T7 = 350-450 deg C.

[0008] The titanium-alloy ingot is obtained by melting in a vacuum consumable-electrode arc furnace.

[0009] The titanium-alloy ingot is obtained by three successive vacuum consumable-electrode arc melts. After melting, cool the ingot in a water-cooled copper crucible. Control the cooling-water inlet temperature within 25-28 deg C and the outlet temperature within 28-31 deg C. Adjust the water flow so that the outlet-inlet temperature difference is less than 3 deg C. The cooling time is t1 = k1 D, where k1 is the cooling coefficient and D is the ingot diameter. After cooling, remove the ingot from the crucible and wrap it in asbestos, or place it in an electric furnace at no more than 400 deg C and furnace-cool to room temperature.

[0010] For extrusion breakdown A, preheat the extrusion die to 300 deg C, maintain an extrusion ratio of 4-8 and an extrusion time below 8 s, and keep the extrusion-exit temperature at or above T_beta + 40 deg C. After extrusion, remove the billet from the equipment and air-cool to room temperature.

[0011] Before extrusion breakdown A and B, hold the titanium-alloy ingot at temperature for t2 = k2 D, where k2 is the holding coefficient and D is the ingot diameter.

[0012] In the detailed operation, the process parameters for preparing titanium-alloy ingots by three vacuum consumable-electrode arc melts are controlled as shown in Table 1.

[0013] The parameters for extrusion breakdown A and B are controlled as shown in Table 2.

[0014] The pulsed-current heat-treatment process A and B principally comprises two solution treatments in the beta phase field, one solution treatment in the alpha + beta phase field, and one ageing treatment in the alpha + beta phase field.

[0015] The above solution combines extrusion breakdown and pulsed-current heat treatment to produce homogeneous, high-strength titanium-alloy bars; the route is shown in Figure 3. Extrusion breakdown A/B breaks up the as-cast titanium-alloy structure to obtain alpha-lamellar basketweave and equiaxed structures. Pulsed-current heat treatment uses the electrical resistance of the material to heat and soften it and improve its flow. Local Joule heating in internal defect regions compensates for nonuniform temperature fields caused by low thermal conductivity and surface heat loss. Collisions between current-carrying electrons and vacancies or atoms increase elemental diffusion and dislocation movement, promoting uniform microstructural evolution.

[0016] Specifically, high-purity grade-0 sponge titanium with uniform particle size is melted three times in a vacuum consumable-electrode arc furnace to obtain an ingot. Extrusion breakdown A at 1050-1150 deg C breaks up the as-cast structure, and air cooling to room temperature produces a coarse alpha-lamellar basketweave structure. Pulsed-current heating provides solution treatment A in the beta phase field. Self-resistance heating promotes uniform alloy-element distribution, dissolution of precipitates and spheroidization of alpha lamellae; local Joule heating also promotes the closure and elimination of internal microcracks, micropores, shrinkage porosity and shrinkage cavities. Extrusion breakdown B in the range T_beta + 50 deg C to T_beta + 150 deg C breaks up the coarse alpha lamellae and produces dynamic spheroidization of alpha in that temperature range. Pulsed current is reapplied to heat into the beta field at T_beta + 30 deg C to T_beta + 60 deg C for solution treatment B. Self-resistance and local Joule heating further promote alpha-lamella spheroidization and homogenization of structure and composition. Pulsed current is reapplied to heat into the alpha + beta two-phase field at T_beta - 100 deg C to T_beta - 10 deg C for solution treatment C, controlling the volume fraction of primary equiaxed alpha through the solution-treatment temperature. Finally, pulsed current heats the material to 350-450 deg C for ageing, controlling precipitate type, morphology and size to obtain homogeneous, high-strength titanium-alloy bars.

[0017] Thus, homogeneous, high-strength titanium-alloy bars are produced, with improved microstructural uniformity and mechanical properties to address aerospace-fastener performance requirements.

[0018] The following advantages are specified.

[0019] 1. The conventional route is titanium-alloy ingot, repeated open-die forging breakdown (five heats), forging or rolling, machining, and repeated heat treatment (at least three cycles). The proposed route is titanium-alloy ingot, first extrusion breakdown (one heat), pulsed-current solution treatment, second extrusion breakdown (one heat), pulsed-current solution treatment, another pulsed-current solution treatment, and pulsed-current ageing. The proposed process has a shorter cycle and a simpler route, reducing transfer time between heats.

[0020] 2. Compared with conventional open-die forging breakdown, extrusion subjects the ingot to triaxial compression and substantially increases the efficiency of breaking up the as-cast structure, reducing five forging heats to two extrusion heats. Extrusion also permits precise temperature and billet-dimension control, reduces machining removal and substantially improves material utilization.

[0021] 3. Pulsed-current heat treatment is more efficient than conventional heat treatment. Its solution-treatment or ageing temperature is 50-100 deg C lower, saving energy. Local Joule heating promotes closure of microdefects, including microcracks, micropores, shrinkage porosity and shrinkage cavities, improving internal quality. Collisions between electrons and elemental atoms increase the efficiency of static spheroidization of alpha lamellae. Pulsed-current heat treatment also improves temperature uniformity in the bar.

Brief description of the drawings

[0022] Figure 1 is the conventional process flow for titanium-alloy bar blanks.

[0023] Figure 2 shows the microstructure of titanium-alloy bar blanks prepared by the conventional process.

[0024] Figure 3 shows the process for preparing titanium-alloy bars according to the invention.

[0025] Figure 4 compares metallographic structures of Ti6554 bars made conventionally and by Example 1.

[0026] Figure 5 compares metallographic structures of Ti55531 bars made conventionally and by Example 2.

Detailed embodiments

[0027] To clarify the objectives and advantages, the invention is described below with reference to examples. The following text describes one or several embodiments and does not strictly limit the specific scope of protection requested.

[0028] All titanium-alloy ingots used in the invention are obtained by three vacuum consumable-electrode arc melts.

[0029] After melting, cool the ingot in a water-cooled copper crucible. Strictly control cooling-water temperature and cooling time. The inlet temperature is 25-28 deg C and the outlet temperature is 28-31 deg C. Control water flow by maintaining the outlet-inlet temperature difference below 3 deg C. Cooling time t1, in minutes, is t1 = k1 D. The cooling coefficient k1 is 0.25-0.5: use a smaller value for smaller ingots and a larger value for larger ingots. D is the ingot diameter in millimetres. At the end of cooling, promptly remove the ingot from the crucible, wrap it in asbestos, or put it in an electric furnace at no more than 400 deg C and furnace-cool to room temperature.

[0030] Heat the ingot with the furnace to 1050-1150 deg C and hold. Holding time t2, in minutes, is t2 = k2 D, where k2 is the holding coefficient; the empirical value for titanium alloy is 0.6, and D is the ingot diameter in millimetres. After holding, transfer the ingot rapidly to the press within 1 minute for one extrusion. To break up the as-cast structure adequately, control the extrusion ratio within 4-8, the extrusion time below 8 s, and the exit temperature at or above T_beta + 40 deg C. Flame-preheat the die to 300 deg C. After extrusion, remove the billet and air-cool to room temperature.

[0031] After the above operations, pass pulsed current through the extruded ingot and heat it into the beta phase field at T_beta + 30 deg C to T_beta + 60 deg C. Hold for solution treatment, then air-cool to room temperature to obtain a coarse alpha-lamellar basketweave structure.

[0032] Reheat the heat-treated bar with the furnace to T_beta + 50 deg C to T_beta + 150 deg C and hold for the time calculated from t2 = k2 D. Then rapidly transfer it to the extrusion equipment for one extrusion. This extrusion breaks up the alpha lamellae and promotes dynamic spheroidization of fragmented alpha during high-temperature extrusion deformation, producing a bimodal structure with equiaxed alpha. After extrusion, remove the material and air-cool to room temperature.

[0033] After the above extrusion, when air cooling reaches 300 deg C, pass pulsed current through the bar again and heat it into the beta phase field at T_beta + 30 deg C to T_beta + 60 deg C for solution treatment, further promoting spheroidization of alpha lamellae.

[0034] After that solution treatment, continue pulsed-current heating into the alpha + beta phase field at T_beta - 100 deg C to T_beta - 10 deg C for another solution treatment. Control the volume fraction of primary equiaxed alpha through the solution-treatment temperature.

[0035] After the above steps, apply pulsed current again and heat to 350-450 deg C for ageing. Control precipitate type, morphology and size to obtain homogeneous, high-strength titanium-alloy bars.

[0036] Example 1: preparation of Ti6554 bars.

[0037] The chemical composition of the Ti6554 titanium alloy, in mass %, is chromium 5.7, molybdenum 4.7, vanadium 4.8, aluminium 3.9, iron 0.08, silicon 0.028, carbon 0.025, and titanium balance. Its phase-transformation temperature T_beta is 820 deg C. It is a high-strength, high-toughness near-beta titanium alloy with a high alloy-element content. Therefore, three vacuum consumable-electrode arc melts are used to produce a 70 kg ingot (diameter 170 mm x length 200 mm). The specific melting parameters are given in Table 1.

[0038] Heat the 70 kg ingot to 1100 deg C, hold for 2 hours, and quickly transfer it to the extrusion equipment. Carry out extrusion breakdown A according to Table 2 to obtain a bar of diameter 60 mm. Apply pulsed current and complete solution treatment A according to Table 3. Then carry out extrusion breakdown B according to Table 2 to obtain a diameter-20 mm bar. Complete solution treatment B, solution treatment C and ageing sequentially according to Table 3.

[0039] Table 1. Process parameters for three vacuum consumable-electrode arc melts of titanium-alloy ingots.

[0040]

Process parameter	First melt	Second melt	Third melt
Vacuum before melting (Pa)	<= 1.33 x 10^-2	<= 1.33 x 10^-2	<= 1.33 x 10^-2
Arc-starting current (kA)	1	2.4	2.8
Arc-stabilizing current (A)	1.5	1.5	1.5
Melting current (kA)	1.0-1.2	2.0-2.7	3.0-3.5
Melting voltage (V)	20-25	22-28	22-28
Vacuum during melting (Pa)	<= 6.67 x 10^-1	<= 6.67 x 10^-1	<= 6.67 x 10^-1
Inlet-water temperature (deg C)	<= 25	<= 25	<= 25
Outlet-water temperature (deg C)	<= 30	<= 30	<= 30
Cooling time (min)	>= 20	>= 50	>= 90

[0041] Table 2. Extrusion-breakdown process parameters for titanium-alloy ingots.

[0042]

Parameter	Extrusion breakdown A	Extrusion breakdown B
Initial diameter (mm)	170	60
Diameter after extrusion (mm)	60	20
Extrusion ratio	8	9
Heating temperature (deg C)	1130	950
Holding time (h)	2.3	1.5
Furnace-exit temperature (deg C)	1100	920
Material-transfer time (s)	51.36	44.10
Container-entry temperature (deg C)	1000	880
Extrusion-exit temperature (deg C)	935	840
Extrusion time (s)	4	4.5
Extrusion force (tonnes)	1800	1800

[0043] Table 3. Pulsed-current heat-treatment parameters during Ti6554 titanium-alloy extrusion.

[0044]

Parameter	Solution A	Solution B	Solution C	Ageing
Current density (A/mm^2)	2.37-2.46	2.37-2.46	2.21-2.35	1.67-1.78
Duty cycle	0.5	0.5	0.5	0.5
Frequency	1	1	1	1
Heating time (s)	600	600	600	600
Holding time (s)	3600	2400	2400	28800

[0045] Example 2: preparation of Ti55531 bars.

[0046] The chemical composition of Ti55531 titanium alloy, in mass %, is aluminium 5.3, molybdenum 5.2, vanadium 5.2, chromium 2.65, zirconium 1.02, and titanium balance. Its phase-transformation temperature T_beta is 850 deg C. It is a high-strength, high-toughness near-beta titanium alloy with high alloy-element content. Three vacuum consumable-electrode arc melts therefore produce a 70 kg ingot (diameter 170 mm x length 200 mm), using the melting parameters in Table 1.

[0047] Heat the 70 kg ingot to 1100 deg C, hold for 2 hours and quickly transfer it to the extrusion equipment. Carry out extrusion breakdown A according to Table 2 to obtain a diameter-60 mm bar. Apply pulsed current to complete solution treatment A according to Table 4. Then carry out extrusion breakdown B according to Table 2 to obtain a diameter-20 mm bar. Carry out solution treatment B, solution treatment C and ageing sequentially according to Table 4.

[0048] Table 4. Pulsed-current heat-treatment parameters during Ti55531 titanium-alloy extrusion.

[0049]

Parameter	Solution A	Solution B	Solution C	Ageing
Current density	2.45-2.51	2.45-2.51	2.35-2.42	1.78-1.88
Duty cycle	0.5	0.5	0.5	0.5
Frequency	1	1	1	1
Heating time (s)	600	600	600	600
Holding time (s)	3600	2400	2400	28800

[0050] Examine the microstructures of the titanium-alloy bars prepared in Examples 1 and 2 using conventional metallographic preparation and etching. The etchant is hydrofluoric acid, nitric acid and water in a volume ratio of 1:2:5. Observe the microstructure by optical microscopy and scanning electron microscopy, and analyse grain size and phase volume fraction with Image-pro software. Compare these microstructures with conventionally prepared bars, as shown in Figures 4 and 5. The bars prepared by extrusion breakdown and pulsed-current heat treatment show better microstructural uniformity than those prepared conventionally.

[0051] The foregoing describes preferred embodiments only. A person of ordinary skill in the art may make improvements and modifications without departing from the principles of the invention, and these should also be regarded as within its scope of protection. Structures, devices and operating methods not specifically described or explained are implemented by conventional means in the field unless otherwise specified or limited.

Drawings - English reference edition

Figure 1. Conventional titanium-alloy bar-blank process.

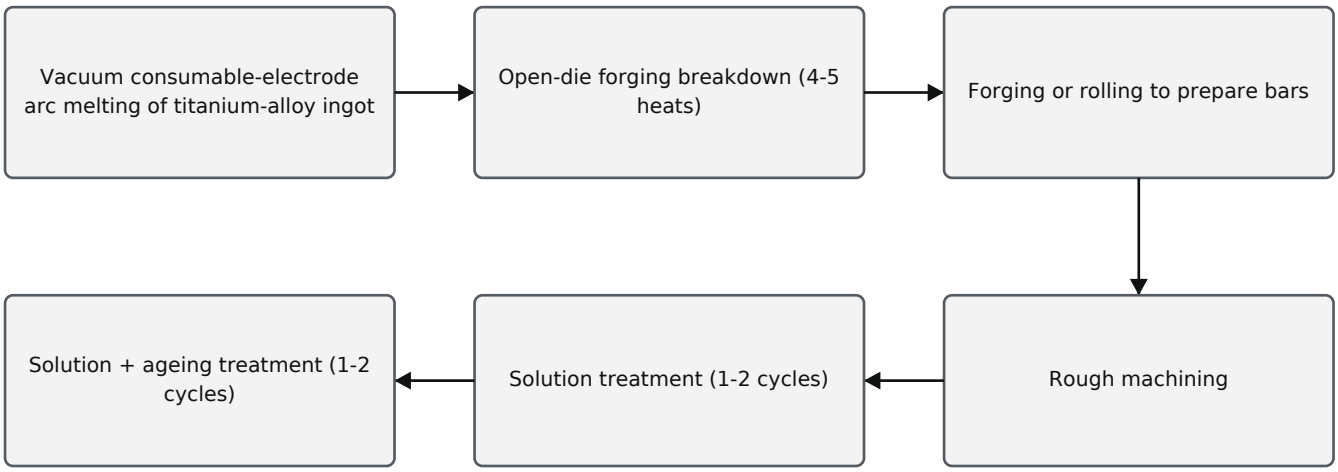
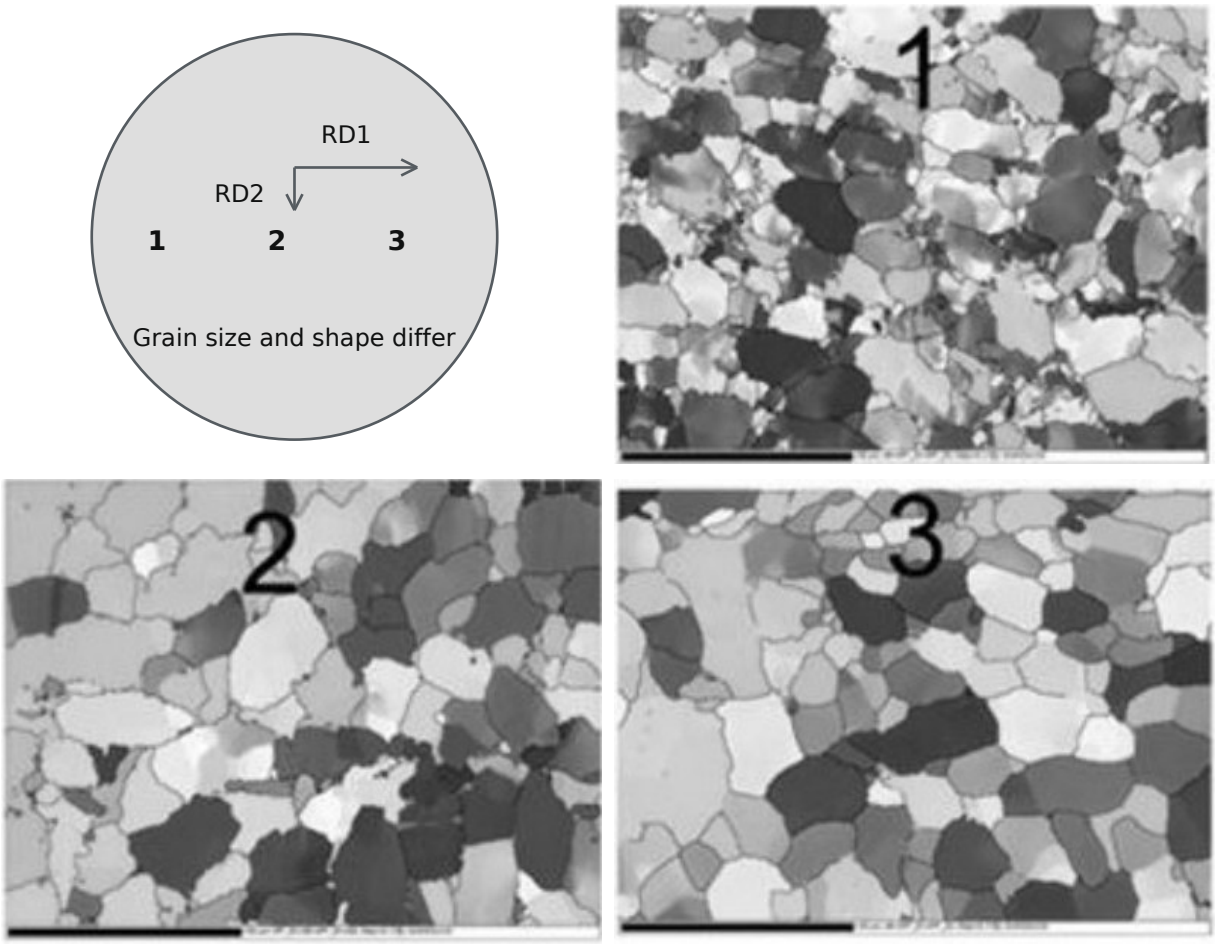


Figure 2. Microstructure of conventionally prepared titanium-alloy bar blanks.



Locations 1, 2 and 3 in the cross-section are shown in the corresponding micrographs. The source schematic labels the two directions RD1 and RD2. Grain size and shape differ across the section.

Figure 3. Process of the invention.

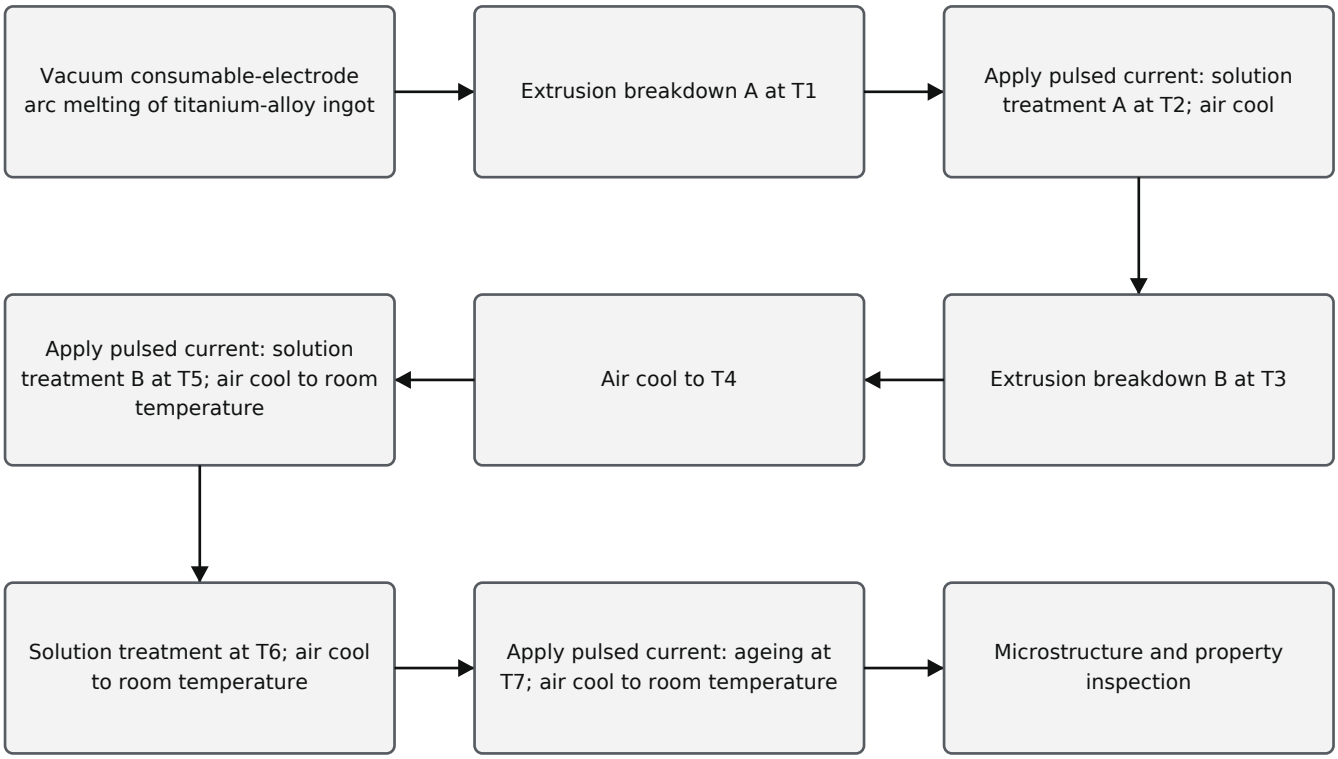
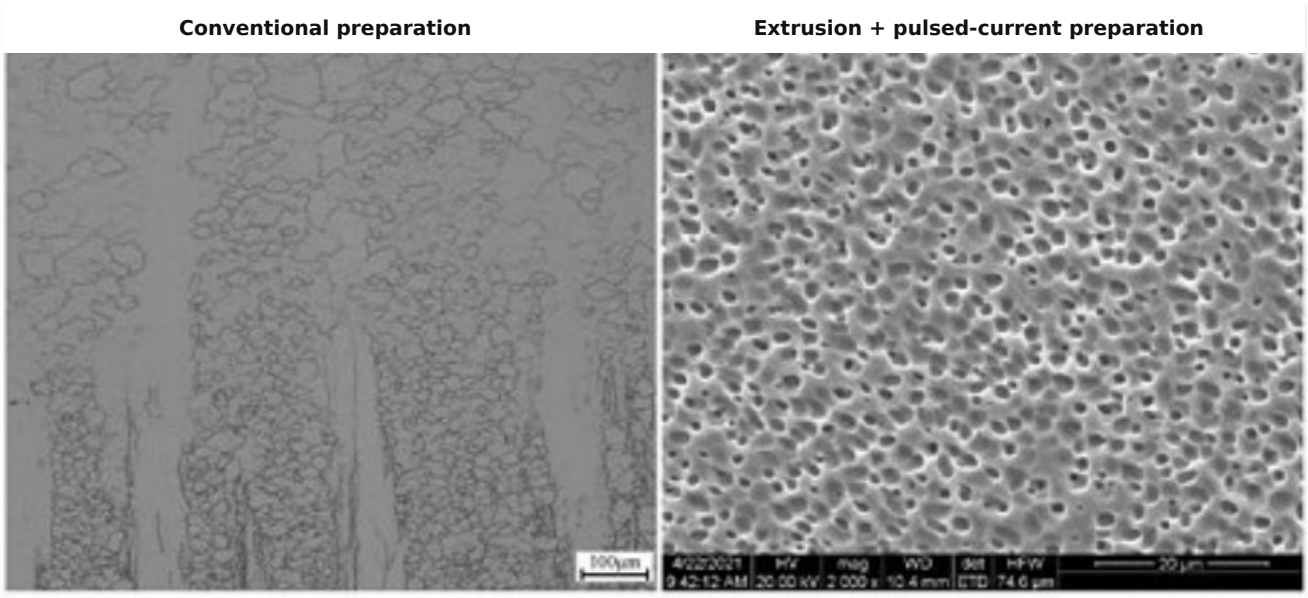


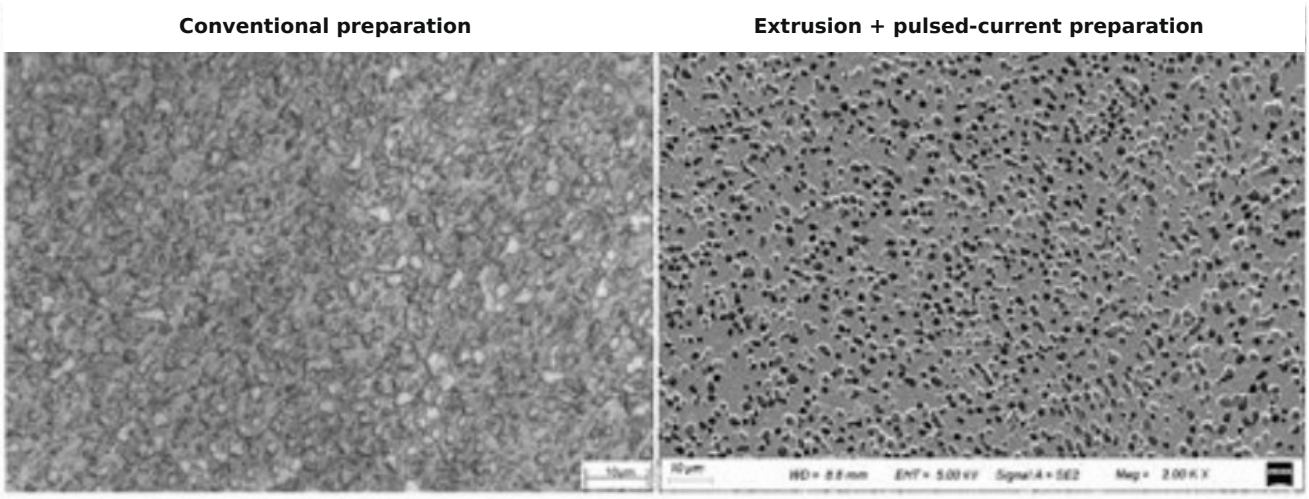
Figure 3 redraw preserves the sequence and the pulsed-current callouts shown in the original drawing. The detailed description also specifies pulsed-current heating for treatment C.

Figure 4. Ti6554 bar microstructures: conventional preparation and Example 1.



Original micrographs and scale bars retained. Chinese method labels are replaced by English annotations.

Figure 5. Ti55531 bar microstructures: conventional preparation and Example 2.



Original micrographs and scale bars retained. Chinese method labels are replaced by English annotations.