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Forging method to improve anisotropy and strength-toughness matching in ultra-high-strength, high-toughness beta titanium alloys

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Abstract

The invention belongs to hot working of novel beta titanium alloys and specifically concerns a forging method that improves anisotropy and strength-toughness matching in ultra-high-strength, high-toughness beta titanium alloys. The method includes homogenising bar at (Tβ + 30) to (Tβ + 100) °C for 15-30 h; high-temperature upsetting and drawing with changes of direction, reducing the heating temperature by 20-50 °C in successive heats within the range (Tβ + 30) to (Tβ + 100) °C; forging to prepare a billet; and isothermal forging of the billet to produce a forging. The disclosed beta titanium-alloy forging specification substantially improves TB17 anisotropy while achieving a favourable balance of strength, ductility and toughness.

Claims

1. A forging method to improve anisotropy and strength-toughness matching in ultra-high-strength, high-toughness beta titanium alloys, comprising: homogenise bar at (Tβ + 30) to (Tβ + 100) °C for 15-30 h; perform high-temperature upsetting and drawing with changes of direction, lowering the heating temperature by 20-50 °C at each successive heat within (Tβ + 30) to (Tβ + 100) °C; forge to prepare a billet; and isothermally forge the billet to obtain the forging.

2. The method of claim 1, wherein high-temperature upsetting and drawing with changes of direction comprises: first heat, heat according to (Tβ + 30) to (Tβ + 100) °C × (0.4-0.8) min/mm, upset and then change direction for drawing, control upsetting deformation to 45%, and chamfer to an octagonal section; second heat, heat according to (Tβ + 30) to (Tβ + 80) °C × (0.4-0.8) min/mm, upset and change direction for drawing, control upsetting deformation to 40%, and chamfer to an octagonal section; third heat, heat according to (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm, perform one upsetting and one drawing operation, control upsetting deformation to 35%, and chamfer to an octagonal section.

3. The method of claim 1, wherein billet preparation comprises: when reheating hot stock is not involved, use (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm for every heat, control deformation per heat to 35%, and draw to billet size; when hot stock returns to the furnace, use that same specification for the first heat and (Tβ + 30) to (Tβ + 50) °C × (0.2-0.4) min/mm for subsequent heats, control deformation per heat to 35%, and draw to billet size.

4. The method of claim 1, wherein isothermal forging uses (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm, upsetting along the thickness direction with deformation controlled at about 30% and a press-down speed of 0.1-5 mm/s.

5. The method of claim 1, wherein the surface is coated with an anti-oxidation coating during homogenisation.

6. The method of any of claims 1-5, wherein all heating is performed in an electric furnace.

7. The method of any of claims 1-5, wherein all billet transfer times are ≤60 s, the forging deformation process takes no more than 5 min, and the finish-forging temperature after deformation is not below 750 °C.

8. The method of claim 1, wherein the forging method is open-die forging.

Description

Original paragraph identifiers are retained for comparison. Tables are re-typeset in English; original values and reported inconsistencies are preserved.

[0001] Technical field. The invention concerns hot working of novel beta titanium alloys, specifically a forging method for improving anisotropy and strength-toughness matching in ultra-high-strength, high-toughness beta titanium alloys.

[0002] Background. Metastable beta titanium alloys are suitable structural titanium-alloy materials because of their high specific strength, deep hardenability, good corrosion resistance, excellent cold and hot formability, and favourable strength-ductility-toughness matching obtainable through strengthening heat treatment. In recent years they have been widely used domestically and internationally in important fields including defence and aerospace.

[0003] TB17 is a new metastable beta titanium alloy independently developed in China with independent intellectual-property rights. After heat treatment its strength can exceed 1260 MPa while retaining a favourable strength-ductility-toughness balance, making it a promising ultra-high-strength, high-toughness alloy for aviation structures. Actual TB17 production, however, frequently encounters pronounced mechanical anisotropy and an unsatisfactory strength-toughness balance, failing to meet aircraft-manufacturing needs for titanium-alloy forgings or parts. Appropriate selection of the principal process and hot-working parameters is therefore important for improving these characteristics.

[0004] Disclosure of the invention. The objective is to provide a forging method that improves anisotropy and strength-toughness matching in an ultra-high-strength, high-toughness beta titanium alloy. Homogenisation, high-temperature upsetting and drawing with direction changes, billet preparation and isothermal forging address the pronounced anisotropy and inadequate property balance of TB17.

[0005] The technical solution is as follows.

[0006] A forging method to improve anisotropy and strength-toughness matching in ultra-high-strength, high-toughness beta titanium alloys comprises the following steps.

[0007] Homogenise the bar at (Tβ + 30) to (Tβ + 100) °C for 15-30 h.

[0008] Perform high-temperature upsetting and drawing with changes of direction. Reduce the heating temperature by 20-50 °C in each successive heat; the heating range is (Tβ + 30) to (Tβ + 100) °C.

[0009] Forge to prepare the billet.

[0010] Isothermally forge the billet to obtain the forging.

[0011] High-temperature upsetting and drawing with changes of direction comprises the following.

[0012] First heat: use (Tβ + 30) to (Tβ + 100) °C × (0.4-0.8) min/mm, upset and then change direction for drawing, control upsetting deformation to 45%, and chamfer to an octagonal section.

[0013] Second heat: use (Tβ + 30) to (Tβ + 80) °C × (0.4-0.8) min/mm, upset and then change direction for drawing, control upsetting deformation to 40%, and chamfer to an octagonal section.

[0014] Third heat: use (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm, perform one upsetting and one drawing operation, control upsetting deformation to 35%, and chamfer to an octagonal section.

[0015] Billet preparation comprises the following.

[0016] When reheating hot stock is not involved, heat according to (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm for every heat; control deformation per heat to 35% and draw to billet dimensions.

[0017] When hot stock returns to the furnace, use (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm for the first heat, and (Tβ + 30) to (Tβ + 50) °C × (0.2-0.4) min/mm for subsequent heats; control deformation per heat to 35% and draw to billet dimensions.

[0018] The heating specification for isothermal forging is as follows.

[0019] Use (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm, upset in the thickness direction, control deformation to about 30%, and use a press-down speed of 0.1-5 mm/s.

[0020] During homogenisation, an anti-oxidation coating is required on the surface.

[0021] All heating is performed in an electric furnace.

[0022] Billet transfer time is ≤60 s, the forging deformation process takes no more than 5 min, and finish-forging temperature after deformation is not below 750 °C.

[0023] The forging method is open-die forging.

[0024] The invention has the following advantages compared with existing technology.

[0025] 1. In conventional forging, the blank is held according to a heating coefficient of 0.4-0.8 and then removed for forging. Here, the forging blank first receives a prolonged, high-temperature homogenisation treatment. This promotes sufficient elemental diffusion and local chemical uniformity; static recrystallisation and growth within the forging become more consistent, improving TB17 microstructural uniformity.

[0026] 2. Conventional low-temperature forging at (Tβ - 40) to (Tβ + 30) °C gives large differences between longitudinal and transverse (chord-direction) properties. Transverse ductility may fall below the specified value and fracture toughness may be low, producing an unsatisfactory strength-toughness balance. The invention adds one isothermal-forging heat after high-temperature upsetting and drawing with direction changes. During isothermal forging, the stress and temperature fields become more uniform, the internal structure undergoes sufficient dynamic recrystallisation and develops a basketweave structure. This improves structural uniformity, reduces mechanical anisotropy and produces a favourable strength-ductility-toughness balance.

[0027] 3. The process is simple, feasible and readily operable. It is particularly suitable for forging ultra-high-strength, high-toughness beta titanium alloys to improve anisotropy and property matching, meeting aircraft-manufacturing needs for titanium-alloy forgings or parts.

[0028] Brief description of the drawings. Figure 1 shows the microstructure of the forging blank in the example.

[0029] Figure 2 shows the microstructure of the final forging in the example.

[0030] Detailed embodiments. The disclosed method for improving anisotropy and strength-toughness matching comprises the following.

[0031] Homogenisation.

[0032] Heat at (Tβ + 30) to (Tβ + 100) °C for 24 h of high-temperature homogenisation; the surface requires an anti-oxidation coating.

[0033] High-temperature upsetting and drawing with changes of direction.

[0034] First heat: heat according to (Tβ + 30) to (Tβ + 100) °C × (0.4-0.8) min/mm, perform one upsetting and one drawing operation with a change of direction, control upsetting deformation to 45%, and chamfer to an octagonal section.

[0035] Second heat: heat according to (Tβ + 30) to (Tβ + 80) °C × (0.4-0.8) min/mm, perform one upsetting and one drawing operation with a change of direction, control upsetting deformation to 40%, and chamfer to an octagonal section.

[0036] Third heat: heat according to (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm, perform one upsetting and one drawing operation, control upsetting deformation to 35%, and chamfer to an octagonal section.

[0037] Billet preparation.

[0038] Heat according to (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm. For hot stock returned to the furnace, the low-temperature holding stage may be omitted and high-temperature holding time is calculated at (0.2-0.4) min/mm. Control deformation per heat to 35% and draw to billet size.

[0039] Isothermal forging.

[0040] Use (Tβ + 30) to (Tβ + 50) °C × (0.4-0.8) min/mm. Upset in the thickness direction, control deformation to about 30%, and use a press-down speed of 5 mm/s.

[0041] The example discloses a forging method to improve anisotropy and strength-toughness matching of ultra-high-strength, high-toughness TB17, principally comprising the following steps.

[0042] Step 1: coat the bar surface with an anti-oxidation coating, heat to (Tβ + 80) to (Tβ + 100) °C and homogenise for 24 h. Figure 1 shows the initial bar microstructure before homogenisation; Table 1 gives the properties.

[0043] Table 1. Mechanical properties of the starting rolled bar.

[0044]

Direction	Tensile strength σb / MPa	0.2% proof stress σ0.2 / MPa	Elongation δ5 / %	Area reduction ψ / %
Longitudinal	1370	1307	11.0	31
Longitudinal	1368	1304	9.0	23
Longitudinal	1364	1301	9.5	30
Longitudinal	1357	1298	11.0	30
Chord	1409	1352	5.0	15
Chord	1415	1350	4.5*	8*
Chord	1435	1389	3.8*	7*

Direction	Tensile strength σb / MPa	0.2% proof stress σ0.2 / MPa	Elongation δ5 / %	Area reduction ψ / %
Chord	1453	1388	3.6*	10*
Source standard	≥1280	≥1150	≥6 / 5	≥12 / 10

Fracture toughness KIC, C-R direction: 40.1 / 40.4 and 36.7 / 36.6 MPa·m^1/2. Source standard row: report measured toughness; elongation and area-reduction minima are longitudinal/chord respectively. Asterisks reproduce the source underlining, which marks data that do not comply with the stated standard value; the 10% area-reduction value remains marked as in the source.

[0045] Step 2: heat the billet according to (Tβ + 80) to (Tβ + 100) °C × 0.4 min/mm. Upset Ø210 × 290 to approximately Ø260 × (189 ± 5), then change direction and draw using four-sided forging to Ø(190 ± 5) × approximately 278; chamfer to a near-octagonal section. Dimensions are in mm.

[0046] Step 3: heat the billet according to (Tβ + 50) to (Tβ + 80) °C × 0.4 min/mm. Upset Ø210 × 290 to approximately Ø260 × (189 ± 5), then change direction and draw using four-sided forging to Ø(190 ± 5) × approximately 278; chamfer to a near-octagonal section. [Translator note: the repeated starting dimensions are retained as printed.]

[0047] Step 4: heat according to (Tβ + 30) to (Tβ + 50) °C × 0.4 min/mm. For hot stock returned to the furnace, the low-temperature holding stage may be omitted; here the source specifies high-temperature holding at 0.4 min/mm. Chamfer and draw Ø(190 ± 5) × approximately 278 to Ø(145 ± 5) × approximately 474; chamfer to a near-octagonal section.

[0048] Step 5: use (Tβ + 30) to (Tβ + 50) °C × 0.4 min/mm; for hot stock returned to the furnace, the low-temperature holding stage may be omitted and high-temperature holding is calculated at 0.4 min/mm. Chamfer and draw Ø(145 ± 5) × approximately 474 to (105 ± 3) × (145 ± 3) × approximately 670.

[0049] Step 6: heat the rough billet according to (Tβ + 30) to (Tβ + 50) °C × 0.4 min/mm. Place it in isothermal flat dies and forge along the 145 mm thickness (ST) direction to a dimension of 100 mm (ST), at a pressing speed of 5 mm/s.

[0050] Step 7: heat-treat the billet obtained in step 6 to obtain the final forging. Figure 2 shows its microstructure and Table 2 its mechanical properties.

[0051] Table 2. Mechanical properties of the final forging.

[0052]

Direction	Tensile strength σb / MPa	0.2% proof stress σ0.2 / MPa	Elongation δ / %	Area reduction ψ / %
L	1286	1157	7	19
L	1275	1159	9	21
LT	1272	1157	9.5	27
LT	1278	1150	9.5	28
ST	1265	1159	9	23
ST	1267	1156	7.5	24
Source standard	≥1260	≥1150	≥6 / 5 / 5	≥12 / 10 / 10

Fracture toughness KIC, T-L direction: 85.6 / 80.7 MPa·m^1/2; source standard: ≥65 MPa·m^1/2. Direction sequence in the standard row is L / LT / ST. Symbol and direction labels are retained from the source.

[0053] Further, the high-temperature upsetting/drawing and billet-preparation deformation operations are carried out on a 1600 T or 2500 T rapid-forging machine. Isothermal forging is carried out on a 100 MN or 200 MN hydraulic press.

Drawings

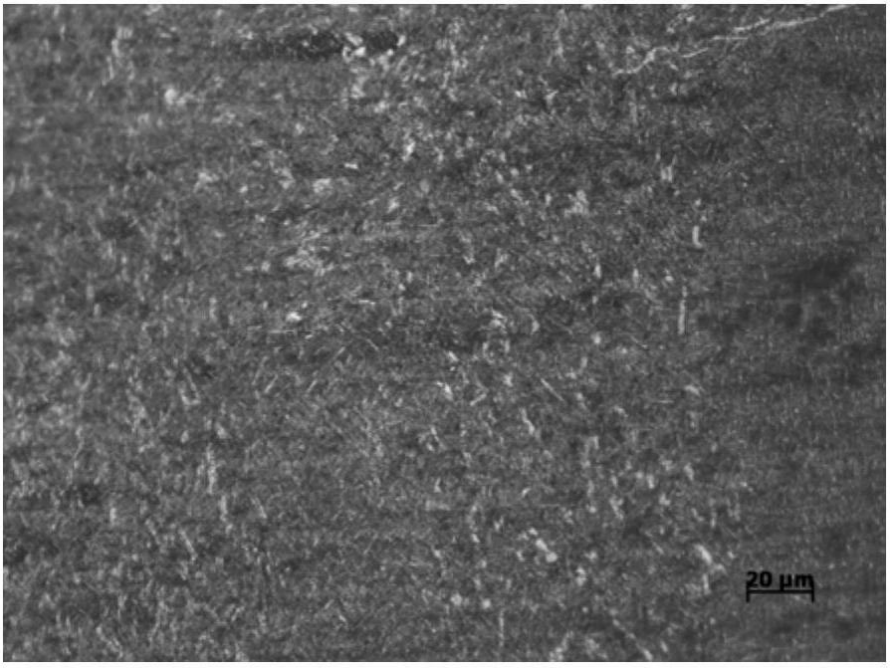


Figure 1. Microstructure of the forging blank before homogenisation (original micrograph; 20 μm scale bar).

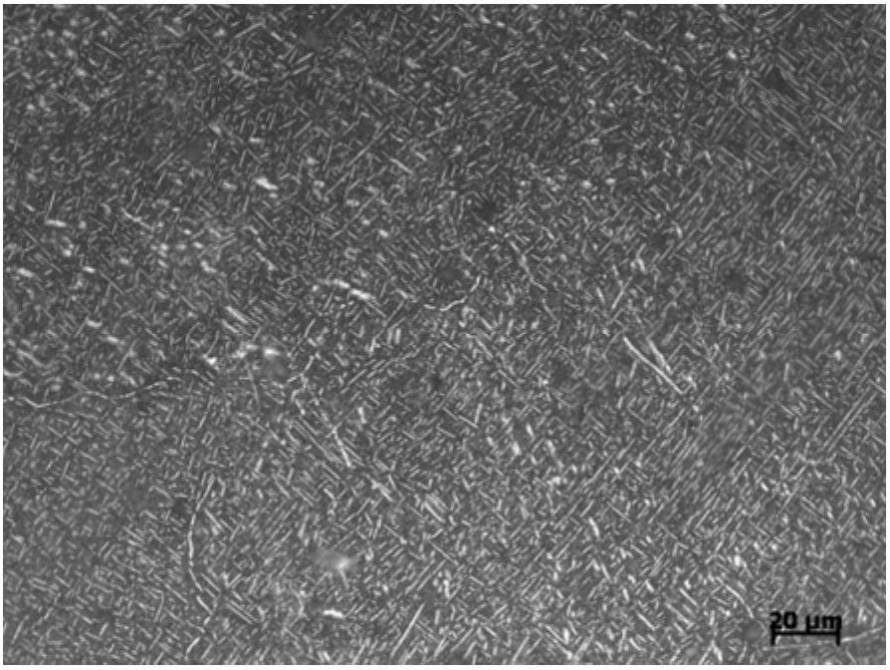


Figure 2. Microstructure of the final forging (original micrograph; 20 μm scale bar).