TB10 | ENGLISH TRANSLATION

# Method for processing forged bars of near-beta TB10 titanium alloy

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## Complete technical reference translation

This English edition reproduces the full abstract, nine claims, all 96 numbered description paragraphs, both examples, all three comparative examples, the complete table and bibliographic information. There are no source drawings. Translation is for reference and is not certified; the original Chinese publication controls. Statements of benefits and performance are statements in the historical patent disclosure, not independent verification, a purchase specification, a material certificate or a TiHubs performance guarantee.

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Patent proprietor: GRIMN Engineering Technology Research Institute Co., Ltd. Address: No. 11 Xingke East Street, Yanqi Economic Development Zone, Huairou District, Beijing 101407, China. Inventors: Wei Yanguang; Tao Haiming; Luo Zheng; Cui Xuefei; Yu Yang; Luo Yumeng; Song Xiaoyun; Li Yanfeng.

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Documents cited on the original cover: CN 111270102 B, 2021-09-10; CN 108504897 B, 2019-02-19; Wei Yanguang, Tao Haiming and Chen Haishan, “Effect of solution temperature on the mechanical properties of TB10 titanium alloy”, Chinese Journal of Rare Metals, 2010, Vol. 34, No. 1, pp. 6-10. Original technical disclosure: one page of claims and six pages of description; no drawings.

## Title

Method for processing forged bars of near-beta TB10 titanium alloy

## Abstract

A method for processing forged bars of near-beta TB10 titanium alloy comprises charge preparation, ingot preparation, breakdown forging, three-direction upsetting and drawing, two-direction upsetting and drawing, microstructure homogenization, low-temperature upsetting and drawing, finish forging, and solution treatment and ageing. The resulting near-beta TB10 forged bar has a diameter of at least 100 mm, tensile strength of at least 1200 MPa, yield strength of at least 1100 MPa, elongation after fracture of at least 12%, and reduction of area of at least 40%. The forged bar has high tensile strength and excellent ductility and may be applied in aviation, aerospace, petroleum, shipbuilding and chemical industries.

## Claims

1. A method for processing forged bars of near-beta TB10 titanium alloy, comprising the following steps: (1) Prepare the near-beta TB10 alloy charge in the following proportions: Mo 4.5-5.5 wt%, V 4.5-5.5 wt%, Cr 1.5-2.5 wt%, Al 2.5-3.5 wt%, Fe <0.30 wt%, C <0.05 wt%, N <0.04 wt%, H <0.015 wt%, O <0.15 wt%, and the balance titanium. (2) Press the charge into an electrode and melt three times in a vacuum consumable-electrode furnace to obtain an ingot. (3) Perform breakdown forging at 980-1030 °C to obtain a square billet. (4) After surface grinding and cutting the square billet, perform three-direction upsetting and drawing for two heats each at 930-950 °C, 890-910 °C and 850-870 °C, with respective deformation amounts of 69-71%, 65-67% and 63-65%, for six heats in total; grind 100% of the surface between each heat. (5) Perform two-direction upsetting and drawing at 790-800 °C, 770-780 °C and 750-760 °C, with respective deformation amounts of 59-61%, 57-58% and 55-56%, for three heats in total; grind 100% of the surface between each heat. (6) Hold in a box-type resistance furnace at 800-850 °C for at least 2 hours, followed by furnace cooling or air cooling. (7) Perform two-direction upsetting and drawing at 700-750 °C, with a deformation amount of at least 50% per pass. (8) Finish-forge at 700-750 °C, forming in a single operation without reheating. (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 700-800 °C for 0.5-3 hours, and age at 400-650 °C for 2-24 hours. (10) Turn the bar surface clean and perform flaw detection; a conforming bar is the finished product.

2. The method according to claim 1, wherein the ingot diameter in step (2) is 550-650 mm.

3. The method according to claim 1, wherein, in step (6), the square billet is charged into a cold box-type resistance furnace, heated to 820-840 °C, held for 2.5-3 hours, and air-cooled.

4. The method according to claim 1, wherein the two-direction upsetting and drawing in step (7) is performed at 710-730 °C with a deformation amount of 51-53%.

5. The method according to claim 1, wherein finish forging in step (8) is performed at 720-740 °C in a single forming operation, and the forged-bar diameter is 140-180 mm.

6. The method according to claim 1, wherein, in step (9), the solution-treatment temperature is 740-760 °C with a holding time of 1-2 hours, and the ageing temperature is 500-550 °C with a holding time of 4-6 hours.

7. The method according to claim 1, wherein the finished-product diameter in step (10) is greater than 100 mm.

8. The method according to claim 1, wherein the finished-product diameter in step (10) is 120-160 mm.

9. A forged bar of near-beta TB10 titanium alloy, characterized in that it is produced by the method according to any one of claims 1-8.

## Description - Technical field

[0001] The invention relates to a method for processing titanium-alloy forged bars, and specifically to a method for producing large-diameter forged bars of near-beta TB10 titanium alloy with high strength and high ductility.

## Background

[0002] High-strength titanium-alloy bars are primarily forged bars of alloys such as TC18, TC21, TB2 and TB6. Processing methods include forging, rolling and radial forging. TC18 has the nominal composition Ti-5Mo-5V-1Cr-5Al-1Fe and the Russian designation BT22. It is a highly alloyed, high-strength near-beta titanium alloy developed in the Soviet Union in the 1970s and combines characteristics of alpha+beta and beta titanium alloys. In the annealed condition, TC18 has nearly equal alpha- and beta-phase fractions and can reach a strength of 1080 MPa; in the double-annealed condition, its strength exceeds 1100 MPa. It is mainly used for large forgings and large integral components. TC21 was developed on the basis of the US Ti-62222S alloy. Its nominal composition is Ti-6Al-2Mo-2Zr-2Sn-2Nb-1.5Cr. It is a weldable, damage-tolerant alpha+beta alloy with high strength (Rm ≥1100 MPa), high fracture toughness (KIC 70-90 MPa·m^1/2) and a relatively low crack-growth rate da/dN. TB6 has the nominal composition Ti-10V-2Fe-3Al and the US designation Ti-1023. Developed by TIMET in 1971, it is described as the most widely used high-strength, high-toughness near-beta titanium alloy to date. After heat treatment, its Rm is 965-1310 MPa and KIC is 99-33 MPa·m^1/2, providing a useful strength-toughness balance. It also has good forgeability and can provide bars, plate and forgings up to 125 mm in section thickness with medium or high strength and high toughness. It has been used in the main landing-gear struts of Boeing 777 and Airbus A380 aircraft. The alloy contains 2% Fe, a slowly reacting eutectoid element, which can cause beta flecks through segregation during melting, limiting its application and development. Timetal555, Ti-5Mo-5V-3Cr-5Al-0.6Fe, also called Ti5553, is a high-strength metastable-beta titanium alloy developed by Boeing and VSMPO on the basis of BT22 by increasing the Cr content. It has high strength and toughness, with strength reaching 1517 MPa, and is described as replacing Ti-1023 in Boeing 777 main landing gear. Its strength-ductility-toughness balance is stated to be better than those of Ti-1023 and BT22, while its higher hardenability suits heat treatment of large forgings. Meanwhile, the newly designed Russian VST55531 alloy, Ti-5Mo-5V-3Cr-5Al-1Zr, was jointly developed by VSMPO and Airbus and applied to the A380. With no Fe addition, beta-fleck formation is fundamentally eliminated. Good hardenability and a good fracture-toughness/strength balance make it suitable for high-strength, high-toughness parts such as pylon fittings, landing gear and landing-gear-to-wing fittings. [Translator note: the final component names are rendered from visibly corrupted wording in the Chinese source; all technical assertions in this background paragraph remain the original disclosure’s statements.]

[0003] Since the 1970s, Ti-5Mo-5V-8Cr-3Al (TB2) and Ti-5Mo-5V-2Cr-3Al (TB10), developed by the Beijing General Research Institute for Nonferrous Metals, have seen the most use. In TB2, Mo, Cr and V chiefly stabilize the beta phase; V also improves ductility. A typical heat treatment is solution treatment slightly above the beta-transus temperature of (800 ±10) °C for 3-30 minutes followed by air cooling, then ageing at (500 ±10) °C for 8-24 hours followed by air or furnace cooling. After this treatment, TB2 has an aged Rm of 1100-1300 MPa and elongation A of approximately 12%, providing high strength and good ductility. For large forgings, however, its high deformation resistance requires forging at 1000 °C, and sufficient deformation across the entire section is still difficult to ensure. TB10 is a high-strength, high-toughness near-beta alloy developed from TB2 by reducing Cr. Its total beta-stabilizer concentration is near the critical level, combining characteristics of alpha+beta and metastable-beta alloys, with high specific strength and good fracture toughness. To obtain good overall properties, solution treatment in the two-phase region followed by secondary ageing is generally used; tensile strength can reach 1350 MPa with elongation after fracture above 6%. TB10 is mainly used for aerospace structural components and can also be used for forged aircraft-fuselage and wing components. On the basis of an assessment of major high-strength, high-toughness titanium alloys in China and abroad, the Beijing General Research Institute for Nonferrous Metals and Baoti Group systematically studied the Ti-Mo-V-Cr-Al system and developed the high-strength, high-toughness metastable-beta alloy BTi-6554, Ti-6Cr-5Mo-5V-4Al. It is described as having an optimum strength-ductility-toughness balance, excellent fatigue resistance and good cold- and hot-workability, making it suitable for large forgings. Developed bars of 9-90 mm diameter reached room-temperature strengths above 1400 MPa after solution treatment and ageing. Bars, wire and large forgings have been successfully applied in aviation and aerospace.

[0004] When the section size of these high-strength titanium alloys (forging-billet thickness or diameter) exceeds 100 mm, tensile strength is usually above 1100 MPa. When tensile strength exceeds 1200 MPa, elongation after fracture is usually no more than 10%. A particular aviation component now requires tensile strength of at least 1200 MPa, yield strength of at least 1100 MPa, elongation after fracture of at least 12%,

and reduction of area of at least 40%.

## Summary of the invention

[0005] To meet the requirements of that aviation component, the invention provides a method for producing near-beta TB10 forged bar with high strength, high elongation and diameter greater than 100 mm.

[0006] To achieve the above objective, the invention includes the following technical solution.

[0007] A method for processing forged bars of near-beta TB10 titanium alloy comprises the following steps.

[0008] (1) Prepare the TB10 charge in the following proportions: Mo 4.5-5.5 wt%, V 4.5-5.5 wt%, Cr 1.5-2.5 wt%, Al 2.5-3.5 wt%, Fe <0.30 wt%, C <0.05 wt%, N <0.04 wt%, H <0.015 wt%, O <0.15 wt%, and the balance titanium.

[0009] (2) Press the charge into an electrode and melt three times in a vacuum consumable-electrode furnace to obtain an ingot.

[0010] (3) Perform breakdown forging at 950-1050 °C to obtain a square billet.

[0011] (4) Perform three-direction upsetting and drawing at 850-950 °C for at least six heats, with a deformation amount of at least 63% in every pass of each upsetting-and-drawing operation.

[0012] (5) Perform two-direction upsetting and drawing at 750-800 °C for at least three heats, with a deformation amount of at least 55% in every pass of each upsetting-and-drawing operation.

[0013] (6) Hold in a box-type resistance furnace at 800-850 °C for at least 2 hours, followed by furnace cooling or air cooling.

[0014] (7) Perform two-direction upsetting and drawing at 700-750 °C, with a deformation amount of at least 50% per pass.

[0015] (8) Finish-forge at 700-750 °C, forming in a single operation without reheating.

[0016] (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 700-800 °C for 0.5-3 hours, then age at 400-650 °C for 2-24 hours.

[0017] (10) Turn the bar surface clean and perform flaw detection; a conforming bar is the finished product.

[0018] Preferably, the charge proportions in step (1) are Mo 4.9-5.3 wt%, V 4.9-5.3 wt%, Cr 1.9-2.3 wt%, Al 2.8-3.3 wt%, Fe <0.25 wt%, C <0.03 wt%, N <0.03 wt%, H <0.01 wt%, O <0.09 wt%, and the balance titanium.

[0019] In step (2), use MoAl master alloy containing 72 wt% Mo, VAl master alloy containing 81 wt% V, pure Cr and Al foil. Mix these uniformly with titanium sponge according to the above charge proportions and press into an electrode.

[0020] In step (2), the ingot obtained after three melts has a diameter of 550-650 mm.

[0021] In step (3), perform breakdown forging at 980-1030 °C to obtain a square billet.

[0022] In step (4), after surface grinding and cutting the square billet, perform three-direction upsetting and drawing for two heats each at 930-950 °C, 890-910 °C and 850-870 °C, with respective deformation amounts of 69-71%, 65-67% and 63-65%, for six heats in total. Grind 100% of the surface between each heat.

[0023] In step (5), perform two-direction upsetting and drawing at 790-800 °C, 770-780 °C and 750-760 °C, with respective deformation amounts of 59-61%, 57-58% and 55-56%, for three heats in total. Grind 100% of the surface between each heat.

[0024] In step (6), charge the square billet into a cold box-type resistance furnace, heat to 820-840 °C, hold for 2.5-3 hours, and air-cool.

[0025] In step (7), perform two-direction upsetting and drawing at 710-730 °C, with a deformation amount of 51-53%.

[0026] In step (8), finish-forge at 720-740 °C in a single forming operation, to a forged-bar diameter of 140-180 mm.

[0027] In step (9), solution-treat at 740-760 °C for 1-2 hours, then age at 500-550 °C for 4-6 hours.

[0028] In step (10), turn the bar surface clean to a finished diameter greater than 100 mm, preferably 120-160 mm, and perform Class A flaw detection. A conforming bar is the finished product.

[0029] In another aspect, the invention includes a forged bar of near-beta TB10 titanium alloy produced by the above method.

[0030] Beneficial effects: the near-beta TB10 forged bar produced by this method is stated to reduce weight by 40% compared with high-strength stainless steel of the same dimensions and strength. Compared with other high-strength titanium-alloy grades, it has a finished diameter greater than 100 mm, tensile strength above 1200 MPa, yield strength above 1100 MPa, elongation after fracture of at least 12%, and reduction of area of at least 40%.

## Detailed embodiments

[0031] The invention is further described below through examples, but is not limited to the contents of the description.

[0032] Example 1

[0033] Preparation of finished bar with diameter 160 mm. The preparation procedure is as follows.

[0034] (1) Prepare the TB10 charge in the following proportions: Mo 4.9 wt%; V 5.1 wt%; Cr 1.9 wt%; Al 3.1 wt%; Fe 0.09 wt%; C 0.006 wt%; N 0.008 wt%; H 0.0011 wt%; O 0.08 wt%; balance titanium.

[0035] (2) Use MoAl master alloy containing 72 wt% Mo, VAl master alloy containing 81 wt% V, pure Cr and Al foil. Mix these uniformly with titanium sponge in the above proportions and press into an electrode. Melt three times in a vacuum consumable-electrode furnace to obtain an ingot of 630 mm diameter.

[0036] (3) Perform breakdown forging at 1030 °C to obtain a square billet with a 500 × 500 mm cross-section.

[0037] (4) After surface grinding and cutting the square billet, perform three-direction upsetting and drawing for two heats each at 950 °C, 900 °C and 850 °C, with respective deformation amounts of 71%, 67% and 63%, for six heats in total. Grind 100% of the surface between each heat.

[0038] (5) Perform two-direction upsetting and drawing at 800 °C, 770 °C and 750 °C, with respective deformation amounts of 61%, 57% and 55%, for three heats in total. Grind 100% of the surface between each heat.

[0039] (6) Charge the square billet into a cold box-type resistance furnace, heat to 840 °C, hold for 2.5 hours, and air-cool.

[0040] (7) Perform two-direction upsetting and drawing at 730 °C, with a deformation amount of 53%.

[0041] (8) Finish-forge at 720 °C in a single forming operation to a forged-bar diameter of 180 mm.

[0042] (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 740 °C for 2 hours, then age at 510 °C for 6 hours.

[0043] (10) Turn the bar surface clean to a finished diameter of 160 mm. Class A flaw detection is passed, producing Sample 1.

[0044] Example 2

[0045] Preparation of finished bar with diameter 120 mm. The preparation procedure is as follows.

[0046] (1) Prepare the TB10 charge in the following proportions: Mo 5.1 wt%; V 5.0 wt%; Cr 2.1 wt%; Al 3.0 wt%; Fe 0.08 wt%; C 0.006 wt%; N 0.008 wt%; H 0.0011 wt%; O 0.06 wt%; balance titanium.

[0047] (2) Use MoAl master alloy containing 72 wt% Mo, VAl master alloy containing 81 wt% V, pure Cr and Al foil. Mix these uniformly with titanium sponge in the above proportions and press into an electrode. Melt three times in a vacuum consumable-electrode furnace to obtain an ingot of 580 mm diameter.

[0048] (3) Perform breakdown forging at 990 °C to obtain a square billet with a 500 × 500 mm cross-section.

[0049] (4) After surface grinding and cutting the square billet, perform three-direction upsetting and drawing for two heats each at 940 °C and 900 °C, with respective deformation amounts of 69% and 65%, and for three heats at 860 °C with a deformation amount of 63%, for seven heats in total. Grind 100% of the surface between each heat.

[0050] (5) Perform two-direction upsetting and drawing for two heats at 800 °C with a deformation amount of 60%, and for two heats at 770 °C with a deformation amount of 57%, for four heats in total. Grind 100% of the surface between each heat.

[0051] (6) Charge the square billet into a cold box-type resistance furnace, heat to 820 °C, hold for 3 hours, and air-cool.

[0052] (7) Perform two-direction upsetting and drawing at 710 °C, with a deformation amount of 51%.

[0053] (8) Finish-forge at 740 °C in a single forming operation to a forged-bar diameter of 140 mm.

[0054] (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 760 °C for 1 hours, then age at 550 °C for 4 hours.

[0055] (10) Turn the bar surface clean to a finished diameter of 120 mm. Class A flaw detection is passed, producing Sample 2.

[0056] Comparative Example 1

[0057] Preparation of finished bar with diameter 160 mm. The preparation procedure is as follows.

[0058] (1) Prepare the TB10 charge in the following proportions: Mo 4.9 wt%; V 5.1 wt%; Cr 1.9 wt%; Al 3.1 wt%; Fe 0.09 wt%; C 0.006 wt%; N 0.008 wt%; H 0.0011 wt%; O 0.08 wt%; balance titanium.

[0059] (2) Use MoAl master alloy containing 72 wt% Mo, VAl master alloy containing 81 wt% V, pure Cr and Al foil. Mix these uniformly with titanium sponge in the above proportions and press into an electrode. Melt three times in a vacuum consumable-electrode furnace to obtain an ingot of 630 mm diameter.

[0060] (3) Perform breakdown forging at 1030 °C to obtain a square billet with a 500 × 500 mm cross-section.

[0061] (4) After surface grinding and cutting the square billet, perform three-direction upsetting and drawing at 900 °C for four heats, with a deformation amount of 67%. Grind 100% of the surface between each heat.

[0062] (5) Perform two-direction upsetting and drawing at 800 °C, 770 °C and 750 °C, with respective deformation amounts of 61%, 57% and 55%, for three heats in total. Grind 100% of the surface between each heat.

[0063] (6) Charge the square billet into a cold box-type resistance furnace, heat to 840 °C, hold for 2.5 hours, and air-cool.

[0064] (7) Perform two-direction upsetting and drawing at 730 °C, with a deformation amount of 53%.

[0065] (8) Finish-forge at 720 °C in a single forming operation to a forged-bar diameter of 180 mm.

[0066] (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 740 °C for 2 hours, then age at 510 °C for 6 hours.

[0067] (10) Turn the bar surface clean to a finished diameter of 160 mm. Class A flaw detection is failed, producing Sample 3.

[0068] Comparative Example 2

[0069] Preparation of finished bar with diameter 120 mm. The preparation procedure is as follows.

[0070] (1) Prepare the TB10 charge in the following proportions: Mo 5.1 wt%; V 5.0 wt%; Cr 2.1 wt%; Al 3.0 wt%; Fe 0.08 wt%; C 0.006 wt%; N 0.008 wt%; H 0.0011 wt%; O 0.06 wt%; balance titanium.

[0071] (2) Use MoAl master alloy containing 72 wt% Mo, VAl master alloy containing 81 wt% V, pure Cr and Al foil. Mix these uniformly with titanium sponge in the above proportions and press into an electrode. Melt three times in a vacuum consumable-electrode furnace to obtain an ingot of 580 mm diameter.

[0072] (3) Perform breakdown forging at 990 °C to obtain a square billet with a 500 × 500 mm cross-section.

[0073] (4) After surface grinding and cutting the square billet, perform three-direction upsetting and drawing for two heats each at 940 °C and 900 °C, with respective deformation amounts of 69% and 65%, and for three heats of upsetting and drawing at 860 °C with a deformation amount of 63%, for seven heats in total. Grind 100% of the surface between each heat. [Translator note: the source omits the direction qualifier for the 860 °C operation in this paragraph.]

[0074] (5) Perform two-direction upsetting and drawing at 770 °C for two heats with a deformation amount of 57%. Grind 100% of the surface between each heat.

[0075] (6) Charge the square billet into a cold box-type resistance furnace, heat to 820 °C, hold for 3 hours, and air-cool.

[0076] (7) Perform two-direction upsetting and drawing at 710 °C, with a deformation amount of 51%.

[0077] (8) Finish-forge at 740 °C in a single forming operation to a forged-bar diameter of 140 mm.

[0078] (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 760 °C for 1 hours, then age at 550 °C for 4 hours.

[0079] (10) Turn the bar surface clean to a finished diameter of 120 mm. Class A flaw detection is passed, producing Sample 4.

[0080] Comparative Example 3

[0081] Preparation of finished bar with diameter 120 mm. The preparation procedure is as follows.

[0082] (1) Prepare the TB10 charge in the following proportions: Mo 5.1 wt%; V 5.0 wt%; Cr 2.1 wt%; Al 3.0 wt%; Fe 0.08 wt%; C 0.006 wt%; N 0.008 wt%; H 0.0011 wt%; O 0.06 wt%; balance titanium.

[0083] (2) Use MoAl master alloy containing 72 wt% Mo, VAl master alloy containing 81 wt% V, pure Cr and Al foil. Mix these uniformly with titanium sponge in the above proportions and press into an electrode. Melt three times in a vacuum consumable-electrode furnace to obtain an ingot of 580 mm diameter.

[0084] (3) Perform breakdown forging at 990 °C to obtain a square billet with a 500 × 500 mm cross-section.

[0085] (4) After surface grinding and cutting the square billet, perform three-direction upsetting and drawing for two heats each at 940 °C and 900 °C, with respective deformation amounts of 69% and 65%, and for three heats of upsetting and drawing at 860 °C with a deformation amount of 63%, for seven heats in total. Grind 100% of the surface between each heat. [Translator note: the source omits the direction qualifier for the 860 °C operation in this paragraph.]

[0086] (5) Perform two-direction upsetting and drawing for two heats at 800 °C with a deformation amount of 60%, and for two heats at 770 °C with a deformation amount of 57%, for four heats in total. Grind 100% of the surface between each heat.

[0087] (6) Charge the square billet into a cold box-type resistance furnace, heat to 820 °C, hold for 3 hours, and air-cool.

[0088] (7) Perform two-direction upsetting and drawing at 710 °C, with a deformation amount of 42%.

[0089] (8) Finish-forge at 740 °C in a single forming operation to a forged-bar diameter of 140 mm.

[0090] (9) Conduct solution treatment and ageing in a box-type resistance furnace: solution-treat at 760 °C for 1 hours, then age at 550 °C for 4 hours.

[0091] (10) Turn the bar surface clean to a finished diameter of 120 mm. Class A flaw detection is passed, producing Sample 5.

## [0092] Table 1

[0093] Room-temperature mechanical properties (Table 1, continued across original pages 7-8).

| Property | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| Rm / MPa | 1240 | 1270 | 1260 | 1250 | 1230 |
| Rp0.2 / MPa | 1150 | 1190 | 1180 | 1180 | 1150 |
| A / % | 13.0 | 16.0 | 9.0 | 11.0 | 10.0 |
| Z / % | 44 | 59 | 31 | 49 | 44 |

[0094] Samples 1-5 were machined into standard bar tensile specimens. Testing was performed on an AG50KNE testing machine, and the room-temperature mechanical properties are shown in Table 1. Comparison shows that all five samples have tensile strength Rm above 1200 MPa and yield strength Rp0.2 above 1100 MPa. Samples 1 and 2, forged according to this invention, have elongation after fracture (A%) above 12% and reduction of area (Z%) above 40%. In contrast, Sample 3 used fewer than six forging heats in step (4), Sample 4 used fewer than three forging heats in step (5), and Sample 5 had less than 50% forging deformation in step (7). Each consequently failed to meet the 12% elongation requirement. Sample 3 also failed Class A flaw detection and had reduction of area below 40%.

[0095] The results show that the near-beta TB10 forged bar produced by the method has tensile strength (Rm) of at least 1200 MPa, yield strength (Rp0.2) of at least 1100 MPa, elongation after fracture of at least 12%, and reduction of area of at least 40%. This titanium-alloy forged bar has high tensile strength and exceptionally good ductility and may be applied in aviation, aerospace, petroleum, shipbuilding and chemical industries.

[0096] The above embodiments are evidently examples provided solely to explain the invention clearly, and do not limit its embodiments. A person skilled in the art may make other changes or variations on the basis of the above description. It is impossible to enumerate every embodiment. Obvious changes or variations derived from the technical solution remain within the scope of protection of the invention.

## Translation notes

Technical meaning: “upsetting and drawing” denotes the repeated forging operations; “heat” denotes a forging heat or reheating cycle. “Without reheating” renders the source term in its single-heat finish-forging context. “Class A flaw detection” is retained without assigning an unstated inspection standard. The numerical ranges in the granted claims and descriptive summary differ in places; both are reproduced as printed, rather than harmonized. No drawing or figure is present in the source. This translation contains every numbered description paragraph [0001]-[0096], all nine claims, the abstract, metadata and Table 1.