TA5 | ENGLISH TRANSLATION

# TA5 titanium alloy plate: manufacture and applications

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## Full technical reference translation

This English edition includes the source abstract, description, claims, all examples, and all tables and drawings present in the technical disclosure. Machine-assisted source text has been reviewed and edited against the Chinese publication. English translation is for reference; the original Chinese publication controls. It is not a certified translation, purchase specification, material certificate, production licence or TiHubs performance guarantee. Original disclosure statements are retained as historical statements, not independently verified current claims.

## Abstract

The invention concerns TA5 titanium-alloy plate, its preparation and applications. Optimising breakdown rolling, surface treatment, second-heat rolling, further surface treatment, third-heat rolling, heat treatment and final surface treatment produces plate with a uniform microstructure, room-temperature Rm >=725 MPa, Rp0.2 >=650 MPa and A >=16%. At D = 3T, the maximum cold-bending angle is 180 degrees, an improvement of 95-100 degrees. It can be used for marine equipment. The equipment and process are simple and suitable for batch production.

## Description

[0001] The invention belongs to the field of titanium-alloy plate manufacture and specifically concerns a TA5 titanium-alloy plate, its preparation method and applications.

[0002] Because of its high strength, corrosion resistance and other favourable characteristics, TA5 titanium alloy is widely used for ship funnel skins, masts and similar components. Cold roll forming is an important process in TA5 plate fabrication, and cold-bending performance is an important measure of plate formability. Under GB/T 3621, TA5 plate no thicker than 5 mm must show no visible surface cracks after a 60-degree bend with mandrel diameter D equal to three times the plate thickness. As marine equipment advances, 60 degrees no longer meets the requirements of high-end equipment, so measures are needed to improve cold-bending performance. Composition, inclusions, microstructure and surface defects are among the principal influences. Research on steel is comparatively mature: the paper “Effects of Slab Quality and Processing on Cold-Bending Performance of Hot-Rolled Plate and Coil” examined composition, metallographic structure and rolling; patent publication CN107937815A obtained steel with good cold-bending performance through composition, hot-rolling and grain-size control. However, measures and methods for improving titanium-alloy cold bending had not been reported in domestic literature or patents. Process optimisation is therefore needed to meet increasingly demanding marine-equipment requirements.

[0003] To overcome the deficiencies of the prior art, the primary objective is to provide a preparation method that optimises key operations and produces TA5 plate with excellent properties.

[0004] A further objective is to provide plate made by that method, with a uniform microstructure, room-temperature tensile strength Rm >=725 MPa, yield strength Rp0.2 >=650 MPa, elongation A >=16%, mandrel diameter D = 3T and maximum cold-bending angle alpha-max = 180 degrees.

[0005] A further objective is to provide applications of the TA5 plate.

[0006] These objectives are achieved by the following technical solution.

[0007] The preparation method comprises the following steps.

[0008] (1) Breakdown rolling: roll the slab to obtain a first-heat plate. Heat to T-beta minus 20-50 degrees C (20-50 degrees C below the ingot transformation temperature), use a holding coefficient of 1.5 +/-0.1 min/mm and a reduction of 40-90%, with finishing temperature >=750 degrees C.

[0009] (2) Surface treatment: treat the surface of the first-heat plate obtained in step (1).

[0010] (3) Second-heat rolling: cross-roll the surface-treated first-heat plate, perpendicular to the first rolling direction. Heat to T-beta minus 50-100 degrees C, use a holding coefficient of 1.3 +/-0.1 min/mm and reduction of 40-85%, with finishing temperature >=600 degrees C. For finished thickness >=5 mm, roll directly to final thickness in this heat and proceed directly to step (6).

[0011] (4) Surface treatment: treat the second-heat plate obtained in step (3).

[0012] (5) Third-heat rolling: unidirectionally roll the surface-treated second-heat plate. Heat to T-beta minus 50-100 degrees C, use a holding coefficient of 1.0 +/-0.1 min/mm and reduction of 40-80%, with finishing temperature >=500 degrees C.

[0013] (6) Heat treatment: anneal the second-heat plate from step (3) or third-heat plate from step (5) in air, then immediately hot-straighten it.

[0014] (7) Surface treatment: treat the heat-treated plate from step (6) to obtain TA5 titanium-alloy plate.

[0015] The preferred surface treatment in step (2) is as follows.

[0016] Grind the entire first-heat plate surface to remove defects such as cracks and indentations. Grind perpendicular to the first rolling direction.

[0017] The preferred surface treatment in step (4) is as follows.

[0018] Sandblast, pickle and grind the second-heat plate described in step (2) to remove defects such as cracks and indentations. Grinding depth must not exceed 10% of plate thickness, and grinding runs parallel to the second rolling direction. [Translator note: the source refers here to step (2); this reference is retained.]

[0019] Preferred annealing conditions in step (6) are 600-700 degrees C for 35-60 min.

[0020] The preferred surface treatment in step (7) is as follows.

[0021] Sandblast, pickle and grind the heat-treated plate from step (6) to remove surface defects such as indentations.

[0022] The preferred material removal by pickling is 0.04-0.06 mm.

[0023] A TA5 titanium-alloy plate is obtained by the above method.

[0024] The TA5 plate is used in marine-equipment manufacture.

[0025] Compared with prior art, the invention has the following advantages and effects.

[0026] (1) Optimisation of the key rolling operations improves cold-bending performance.

[0027] (2) Optimisation of the key annealing operation improves cold-bending performance.

[0028] (3) Optimisation of surface treatment further improves cold-bending performance.

[0029] (4) The resulting TA5 plate has a uniform microstructure, room-temperature tensile strength Rm >=725 MPa, yield strength Rp0.2 >=650 MPa, A >=16%, D = 3T and maximum cold-bending angle 180 degrees, giving excellent combined properties.

[0030] (5) The equipment and process are simple and suitable for batch production.

[0031] Figure 1 shows the microstructure of TA5 plate from Example 1.

[0032] Figure 2 shows the microstructure of TA5 plate from Example 2.

[0033] Figure 3 shows the microstructure of TA5 plate from Comparative Example 1.

[0034] Figure 4 shows the microstructure of TA5 plate from Comparative Example 2.

[0035] Figure 5 shows cold-bent specimens from Examples 1-2 and Comparative Examples 1-2.

[0036] The invention is described further below with examples and drawings, but its embodiments are not limited to these.

## [0037] Example 1

[0038] Breakdown rolling: roll a 140 mm slab into a first-heat plate. The measured ingot transformation temperature is 1010 degrees C; heat to 980 degrees C (T-beta - 30 degrees C), hold at 1.5 +/-0.1 min/mm, roll to 25 mm with 82% reduction and finish at 766 degrees C.

[0039] Surface treatment: grind the entire first-heat plate to remove surface cracks, indentations and other defects, perpendicular to the first rolling direction.

[0040] Second-heat cross rolling: roll the surface-treated first-heat plate perpendicular to its previous rolling direction. Heat to 930 degrees C (T-beta - 80 degrees C), hold at 1.3 +/-0.1 min/mm and roll to 5 mm with 80% reduction, finishing at 682 degrees C.

[0041] Heat treatment: anneal the plate in air at 620 degrees C for 60 min, then hot-straighten immediately after furnace removal.

[0042] Final surface treatment: sandblast, strongly pickle and grind the heat-treated plate to remove indentations and other surface defects, obtaining TA5 plate. Pickling removes approximately 0.04 mm.

[0043] The microstructure, cold-bent specimens and properties are shown in Figure 1, Figure 5 and Table 1, respectively.

## [0044] Example 2

[0045] Breakdown rolling: roll a 120 mm slab into a first-heat plate. The measured ingot transformation temperature is 1000 degrees C; heat to 980 degrees C (T-beta - 20 degrees C), hold at 1.5 +/-0.1 min/mm, roll to 18 mm with 85% reduction and finish at 752 degrees C.

[0046] Surface treatment: grind the entire first-heat plate to remove surface cracks, indentations and other defects, perpendicular to the first rolling direction.

[0047] Second-heat cross rolling: roll the surface-treated first-heat plate perpendicular to its previous rolling direction. Heat to 920 degrees C (T-beta - 80 degrees C), hold at 1.3 +/-0.1 min/mm and roll to 5 mm with 72% reduction, finishing at 608 degrees C.

[0048] Surface treatment: sandblast, strongly pickle and grind the second-heat plate to remove cracks, indentations and other defects. Grinding depth does not exceed 10% of thickness and the grinding direction is parallel to the second rolling direction.

[0049] Third-heat unidirectional rolling: heat the surface-treated second-heat plate to 920 degrees C (T-beta - 80 degrees C), hold at 1.0 +/-0.1 min/mm and roll to the final 3 mm thickness with 40% reduction, finishing at 508 degrees C.

[0050] Heat treatment: anneal the plate in air at 600 degrees C for 35 min, then hot-straighten immediately after furnace removal.

[0051] Final surface treatment: sandblast, strongly pickle and grind the heat-treated plate to remove indentations and other surface defects, obtaining TA5 plate. Pickling removes approximately 0.06 mm.

[0052] The microstructure, cold-bent specimens and properties are shown in Figure 2, Figure 5 and Table 1, respectively.

## [0053] Example 3

[0054] Breakdown rolling: roll a 120 mm slab into a first-heat plate. The measured ingot transformation temperature is 1000 degrees C; heat to 980 degrees C (T-beta - 20 degrees C), hold at 1.5 +/-0.1 min/mm, roll to 18 mm with 85% reduction and finish at 755 degrees C.

[0055] Surface treatment: grind the entire first-heat plate to remove surface cracks, indentations and other defects, perpendicular to the first rolling direction.

[0056] Second-heat cross rolling: roll the surface-treated first-heat plate perpendicular to its previous rolling direction. Heat to 950 degrees C (T-beta - 50 degrees C), hold at 1.3 +/-0.1 min/mm and roll to 5 mm with 72% reduction, finishing at 620 degrees C.

[0057] Surface treatment: sandblast, strongly pickle and grind the second-heat plate to remove cracks, indentations and other defects. Grinding depth does not exceed 10% of thickness and the grinding direction is parallel to the second rolling direction.

[0058] Third-heat unidirectional rolling: heat the surface-treated second-heat plate to 950 degrees C (T-beta - 50 degrees C), hold at 1.0 +/-0.1 min/mm and roll to the final 3 mm thickness with 40% reduction, finishing at 510 degrees C.

[0059] Heat treatment: anneal the plate in air at 620 degrees C for 45 min, then hot-straighten immediately after furnace removal.

[0060] Final surface treatment: sandblast, strongly pickle and grind the heat-treated plate to remove indentations and other surface defects, obtaining TA5 plate. Pickling removes approximately 0.06 mm.

[0061] The properties of the TA5 plate are given in Table 1.

## [0062] Example 4

[0063] Breakdown rolling: roll a 120 mm slab into a first-heat plate. The measured ingot transformation temperature is 1000 degrees C; heat to 950 degrees C (T-beta - 50 degrees C), hold at 1.5 +/-0.1 min/mm, roll to 18 mm with 85% reduction and finish at 763 degrees C.

[0064] Surface treatment: grind the entire first-heat plate to remove surface cracks, indentations and other defects, perpendicular to the first rolling direction.

[0065] Second-heat cross rolling: roll the surface-treated first-heat plate perpendicular to its previous rolling direction. Heat to 900 degrees C (T-beta - 100 degrees C), hold at 1.3 +/-0.1 min/mm and roll to 5 mm with 72% reduction, finishing at 615 degrees C.

[0066] Surface treatment: sandblast, strongly pickle and grind the second-heat plate to remove cracks, indentations and other defects. Grinding depth does not exceed 10% of thickness and the grinding direction is parallel to the second rolling direction.

[0067] Third-heat unidirectional rolling: heat the surface-treated second-heat plate to 900 degrees C (T-beta - 100 degrees C), hold at 1.0 +/-0.1 min/mm and roll to the final 3 mm thickness with 40% reduction, finishing at 505 degrees C.

[0068] Heat treatment: anneal the plate in air at 700 degrees C for 35 min, then hot-straighten immediately after furnace removal.

[0069] Final surface treatment: sandblast, strongly pickle and grind the heat-treated plate to remove indentations and other surface defects, obtaining TA5 plate. Pickling removes approximately 0.05 mm.

[0070] The properties of the TA5 plate are given in Table 1.

## [0071] Comparative Example 1

[0072] A 140 mm slab is used to make TA5 plate. The measured transformation temperature is 1010 degrees C. Finished thickness equals that of Example 1. All process parameters are the same as Example 1 except the following.

[0073] First-heat temperature: 1020 degrees C (T-beta +10 degrees C); second-heat temperature: 980 degrees C (T-beta -30 degrees C).

[0074] The microstructure, cold-bent specimens and properties are shown in Figure 3, Figure 5 and Table 1, respectively.

## [0075] Comparative Example 2

[0076] A 120 mm slab is used to make TA5 plate. The measured transformation temperature is 1000 degrees C. Finished thickness equals that of Example 2. Except for the following parameters, the source states that all other parameters are the same as Example 1. [Translator note: the reference to Example 1 is retained as printed.]

[0077] First-heat temperature: 1010 degrees C (T-beta +10 degrees C); second-heat and third-heat temperatures: 970 degrees C (T-beta -30 degrees C).

[0078] The microstructure, cold-bent specimens and properties are shown in Figure 4, Figure 5 and Table 1, respectively.

## [0079] Performance test example

[0080] Tensile and cold-bending tests were performed on a material testing machine in accordance with GB/T 228 and GB/T 232. Results are given in Table 1.

[0081] Table 1. Properties of TA5 plate in the examples and comparative examples.

[0082] [Table 1, first portion, reproduced below in English.]

[0083] [Table 1, continuation, combined below.]

## Table 1. Room-temperature mechanical properties and cold bending (D = 3T)

| Material | Rm (MPa) | Rp0.2 (MPa) | A (%) | Bend angle |
|---|---|---|---|---|
| GB/T 3621 requirement | >=685 | >=585 | >=12 | >=60 degrees |
| Example 1 | 735-754 | 685-702 | 18-23 | 180 degrees |
| Example 2 | 727-742 | 664-686 | 18.5-24.5 | 180 degrees |
| Example 3 | 729-745 | 671-688 | 18-22 | 180 degrees |
| Example 4 | 740-752 | 689-710 | 17-20.5 | 180 degrees |
| Comparative 1 | 747-788 | 692-743 | 14-18.5 | 75 degrees |
| Comparative 2 | 735-767 | 682-718 | 15-20 | 80 degrees |

[0084] Figures 1-4 show that, compared with Comparative Examples 1 and 2, Examples 1 and 2 have a fine, uniform microstructure. Figure 5 and Table 1 show excellent cold-bending performance for Examples 1-4, with a 95-100 degree increase in the maximum cold-bending angle.

[0085] In summary, the TA5 plate produced by this invention displays excellent combined properties: excellent cold bending, a 95-100 degree increase in maximum bending angle, fine and uniform microstructure, and a good strength-ductility balance.

[0086] The examples above are preferred embodiments, but do not limit the invention. Changes, modifications, substitutions, combinations and simplifications that do not depart from its spirit and principles are equivalent alternatives and fall within its scope of protection.

## Claims (8)

1. A preparation method for TA5 titanium-alloy plate characterised by the following steps:

(1) Breakdown rolling: roll the slab to obtain a first-heat plate. Heat to T-beta minus 20-50 degrees C (20-50 degrees C below the ingot transformation temperature), use a holding coefficient of 1.5 +/-0.1 min/mm and a reduction of 40-90%, with finishing temperature >=750 degrees C.

(2) Surface treatment: treat the surface of the first-heat plate obtained in step (1).

(3) Second-heat rolling: cross-roll the surface-treated first-heat plate, perpendicular to the first rolling direction. Heat to T-beta minus 50-100 degrees C, use a holding coefficient of 1.3 +/-0.1 min/mm and reduction of 40-85%, with finishing temperature >=600 degrees C. For finished thickness >=5 mm, roll directly to final thickness in this heat and proceed directly to step (6).

(4) Surface treatment: treat the second-heat plate obtained in step (3).

(5) Third-heat rolling: unidirectionally roll the surface-treated second-heat plate. Heat to T-beta minus 50-100 degrees C, use a holding coefficient of 1.0 +/-0.1 min/mm and reduction of 40-80%, with finishing temperature >=500 degrees C.

(6) Heat treatment: anneal the second-heat plate from step (3) or third-heat plate from step (5) in air, then immediately hot-straighten it.

(7) Surface treatment: treat the heat-treated plate from step (6) to obtain TA5 titanium-alloy plate.

2. The method of claim 1, wherein step (2) comprises grinding the entire surface of the first-heat plate to remove defects, perpendicular to the first rolling direction.

3. The method of claim 1, wherein step (4) comprises sandblasting, pickling and grinding the second-heat plate stated to be obtained in step (2), with grinding depth no more than 10% of thickness and grinding parallel to the second rolling direction.

4. The method of claim 1, wherein the annealing in step (6) is at 600-700 degrees C for 35-60 min.

5. The method of claim 1, wherein step (7) comprises sandblasting, pickling and grinding the heat-treated plate to remove surface defects.

6. The method of claim 5, wherein pickling removes 0.04-0.06 mm.

7. A TA5 titanium-alloy plate prepared by a method of any of claims 1-6.

8. Use of the TA5 plate of claim 7 in marine-equipment manufacture.

## Drawings and English captions

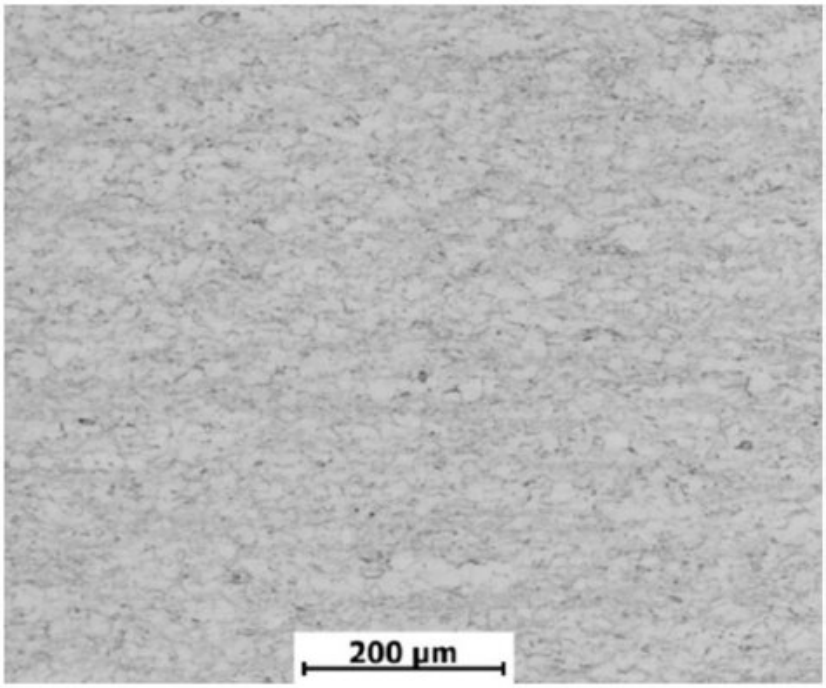



Figure 1. Microstructure, Example 1.

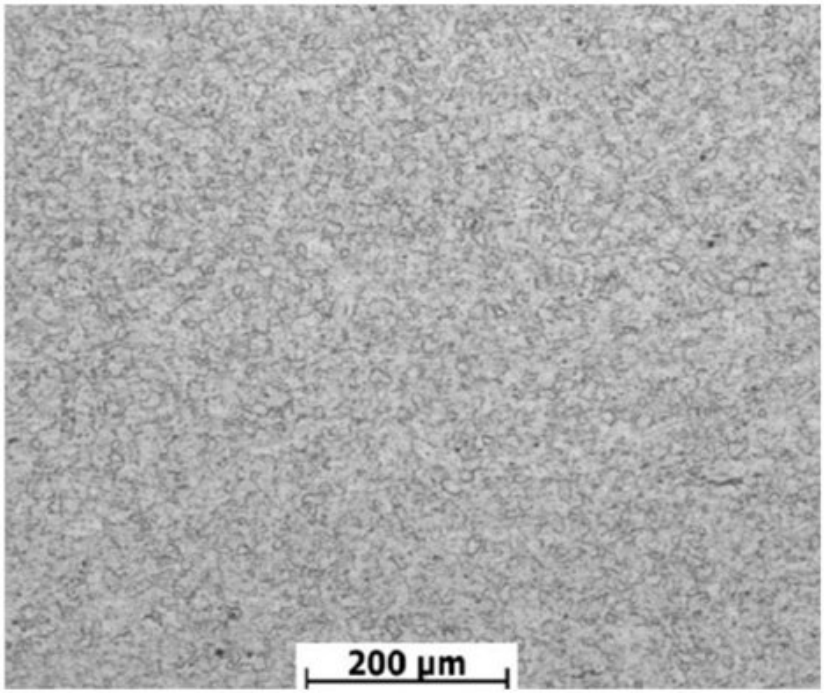



Figure 2. Microstructure, Example 2.

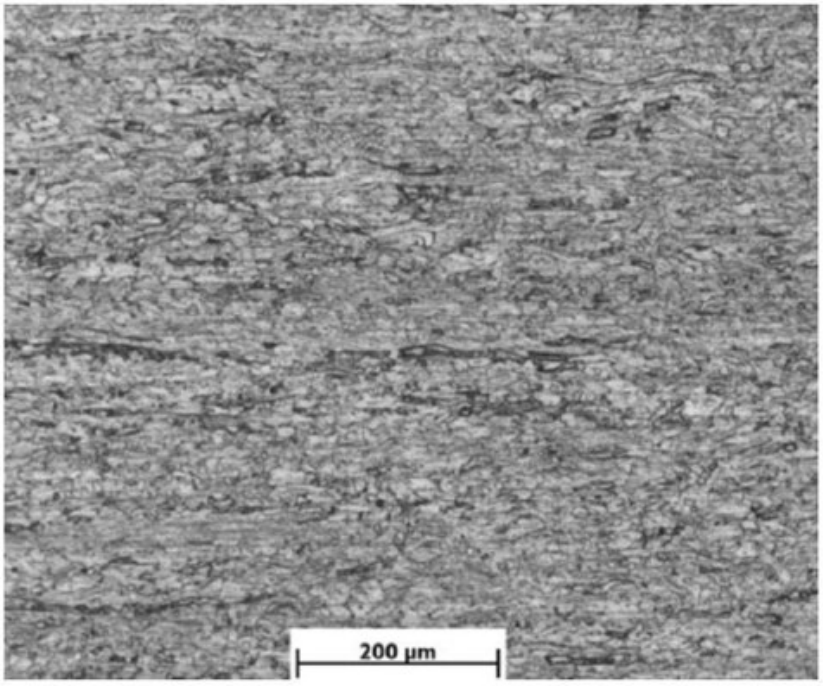



Figure 3. Microstructure, Comparative Example 1.

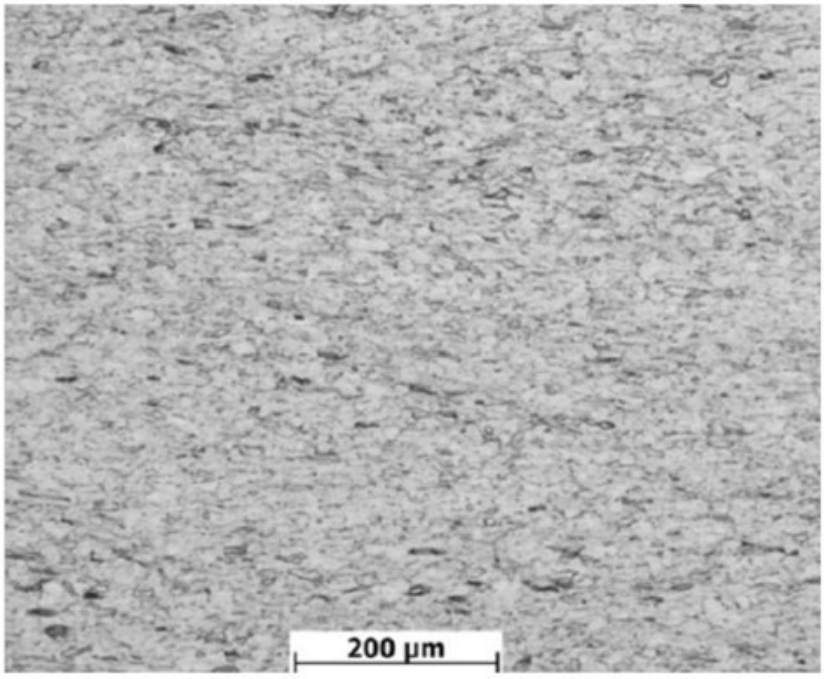



Figure 4. Microstructure, Comparative Example 2.

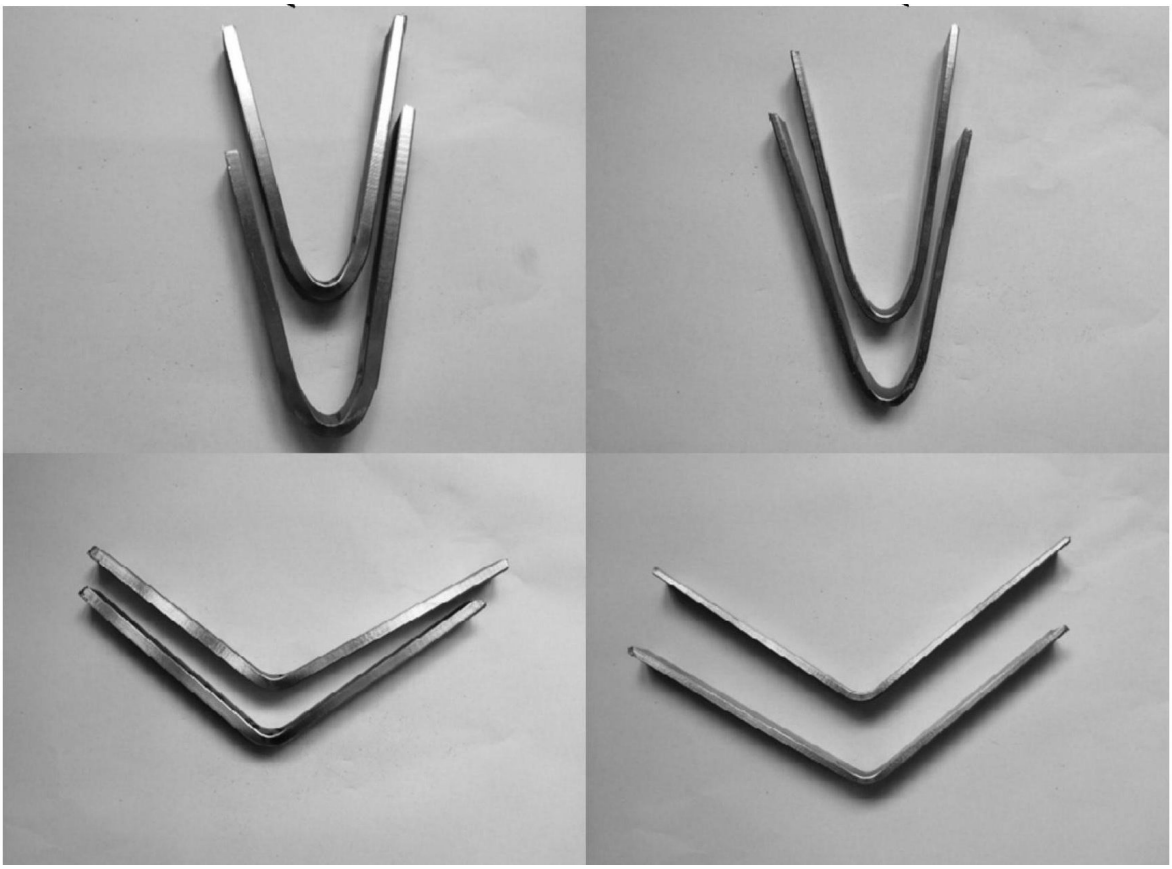


Figure 5. Cold-bent specimens. Top row: Example 1 (left), Example 2 (right). Bottom row: Comparative Example 1 (left), Comparative Example 2 (right). Photograph content is retained; Chinese labels are replaced by this English legend.