FRACTURE MECHANISM OF STRUCTURALLY AND CRYSTALLOGRAPHICALLY TEXTURED TITANIUM BILLETS

M.A. SKOTNIKOVA

Leningrad Institute of Machinebuilding LIM (VTUZ-LMZ).
195197, St. Petersburg, Polustrovskij Pr., 14, Russia

A.S. KUDRJAVTSEV

Central Research Institute of Structural Materials "Prometey".
193167, St. Petersburg, Nabereznaja Reki Monastyrki, 1, Russia

ABSTRACT

A Systematic investigation of fracture features of structurally and crystallographically textured billets in a two-phase Ti-6Al-IV-IMo alloy impact and low cycle tested with a light metallographic, X-ray and scanning electron microscopy was carried out. It is indicated that a reduction of the tensile properties is induced by the structurally and crystallographically precipitated fields of basis orientation of the interface boundaries of 20-30 µm in width spaced across the thickness billet by 100-170 µm.

KEYWORDS

Titanium alloys, structure, impact values, low cycle fatigue, electron microscopy, fracture mechanism.

INTRODUCTION

A fracture of titanium alloy billets at the time of a hot deformation (rolling) is their elevated sensitivity to a temperature and deformation inhomogeneity across the thickness. This induces a concentration inhomogeneity of alloying elements distribution and an inhomogeneity of a recrystallisation process across the thickness of the flat billets, generation of a geometrical oriented (structurally texted) structure. The structure enchances an anisotropy of the tensile properties of flat semiproducts. An addition to structural texture the anisotropy of the properties is influenced by a crystallographic texture of deformation represented by a preffered orientation of elemental hexagonal cells of a crystal lattice of an α-phase influenced by rolling stresses. The present work aims at an investigation of impact and low cycle values of the hot deformed billets of the two-phase Titanium Ti-6Al-IV-IMo alloy with structural and crystallographic texture features of the investigated materials.

IMPACT BEND TEST

Fig.1 shows the location of the impact specimens and notch cutting.

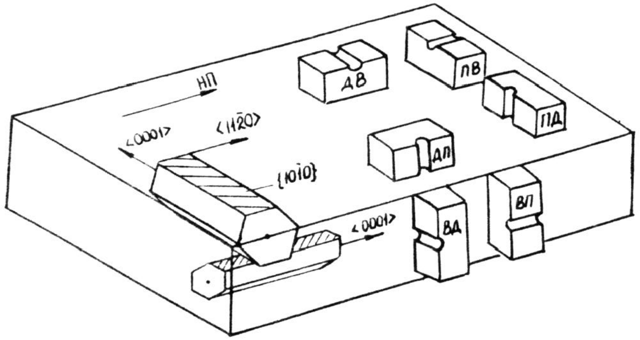

Fig.1. The location of impact specimens and notch cutting in a bulk of a billet.

The test results indicated that the billets were characterized by a pronounced anisotropy of the impact values KCV and KCU and its base component-a crack propagation energy (see table 1).

Table 1. Impact values, KCV, KCU, Mj/m^2 and its components-a crack initiation and a crack propagation energy

Specimen and notch orientation	KCV	KCU	KCU initiation	KCU propagation
ПД	0.51	0.76	0.33	0.43
ВП	0.45	0.57	0.16	0.41
ПВ	0.89	0.92	0.06	0.86
ДП	0.58	0.74	0.21	0.53
ВД	0.73	0.86	0.18	0.68
ДВ	1.29	1.32	0.06	1.26

To explain the results an investigation of a volume morphology of a structural and crystallographic texture of the billets with light metallography, X-ray and electron microscopy was carried out. As X-ray investigations showed in the billets two components texture of a prismatic $\{10\bar{1}0\}$ type with an <0001> axes oriented along and across the rolling direction had generated. An investigation of the billets by colour chemical painting allows to suppose that the components of the crystallographic texture across the full thickness of the billet howe a lamellar structure (fig.2.a). Within the layer sections of the {0001} crystallographic plane of the α-titanium (white colour in the figure) were distributed across the thickness of the billet and <0001> orientation was changed layer by layer and made up 0 degree angle (non-basic component of the order of magnitude of 20%) or 90 degrees (basic component of the order of magnitude of 60%) in respect with the rolling direction.

The metallographic studies showed that in a surface layers of the hot rolled billet the structurally pronounced fields (bands) had formed, the thickness of the bands was 20-30 μm, they consisted of elongated, internormal, flattened in the thickness direction closely packed particles of the α-phase (fig.2.b).

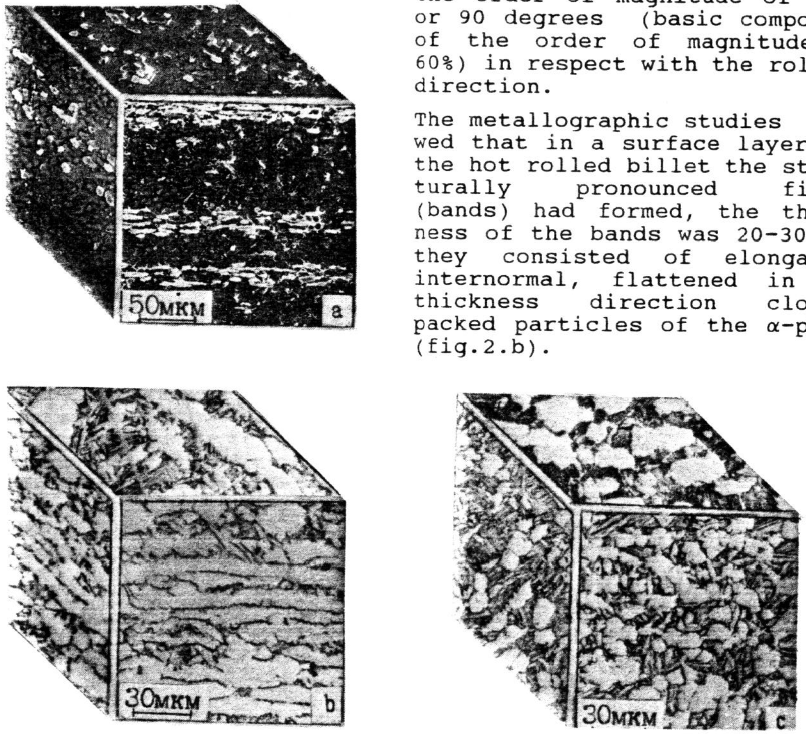

Fig.2. Volume morphology of a crystallographic texture (a) and of a structural in a surface (b) and an axial (c) layers of a billet.

The preferred orientation of the boundaries of these structurally fields makes an angle of 90 degree (basic component). So, in the surface layers of the billet the structurally pronounced fields seemed to be crystallographically pronounced fields of the basic orientation of the interface boundaries which are regularly distributed across its thickness and spaced by 100-170 μm.

In axial layers of the hot rolled structurally pronounced field of the geometrical orientation the boundaries were not observed, in practice. There was observed small chains of rounded recrystallized grains of the α-phase of the basic orientation across the thickness (fig.2.c).

A fractographic investigations of the fracture surfaces of the impact specimens of lamellar structure and of a crystallographic texture allow to understand their fracture mechanisms during the test. The basic micromechanism of a specimen plastic deformation when the applied stress is normal to the <0001> direction is known to be a prismatic sliding in the {10$\bar{1}$0} plain in <11$\bar{2}$0> direction, which induces high values of impact toughness. The deformation of the specimens, where the applied stresses are parallel to <0001> direction is activated by a twinning process along {10$\bar{1}$1} plane, here the impact values are lower. At the time of the fracture the main crack seaks the most easy ways of propagation. As for the investigated billets these directions are: extention direction of the large angle boundaries of structurally pronounced fields out of α-phase primary grains and also a direction along the <0001> crystallographic axis within the grains. The crack propagates by a minimum energy consumption along these indicated orientations (structural and crystallographic). Kolachev (1983) indicates that the energy to initiate a micro crack will be minimum when dislocation mechanism of its initiation in a metal and it is retarded, and crack generation occurs along the inner interfaces preferably.

So, the structural texture of the investigated materials was represented by a preferred orientation of the large angle interface boundaries of the flattened and elongated particles of the α-phase. The crystallographic texture is represented by a preferable orientation of the elemental hexagonal cells of the crystal lattice of the titanium α-phase. Firsts, the effect of structurally and crystallographically pronounced fields elongated along the rolling direction (basic component) on the fracture micro mechanisms of the impact specimens was studied. A contribution of structural texture in these fields is clearly shown on the ПД samples (KCU prop.=0.43 Mj/m^2) where the large angle boundary orientation is coincided to the propagation direction of the main crack (fig.3.a).

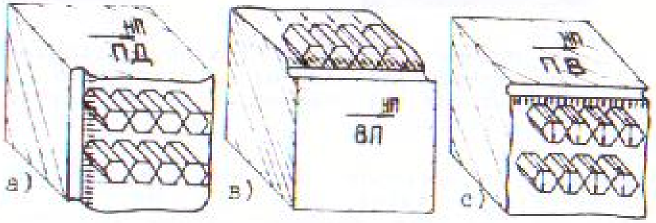

Fig.3. Fracture mechanism of the impact specimens of structural (a), crystallographic (b), and both types texture (c).

The striations - traces of a ductile grain boundaries of these structurally pronounced fields were observed on the surface fracture of these specimens type.

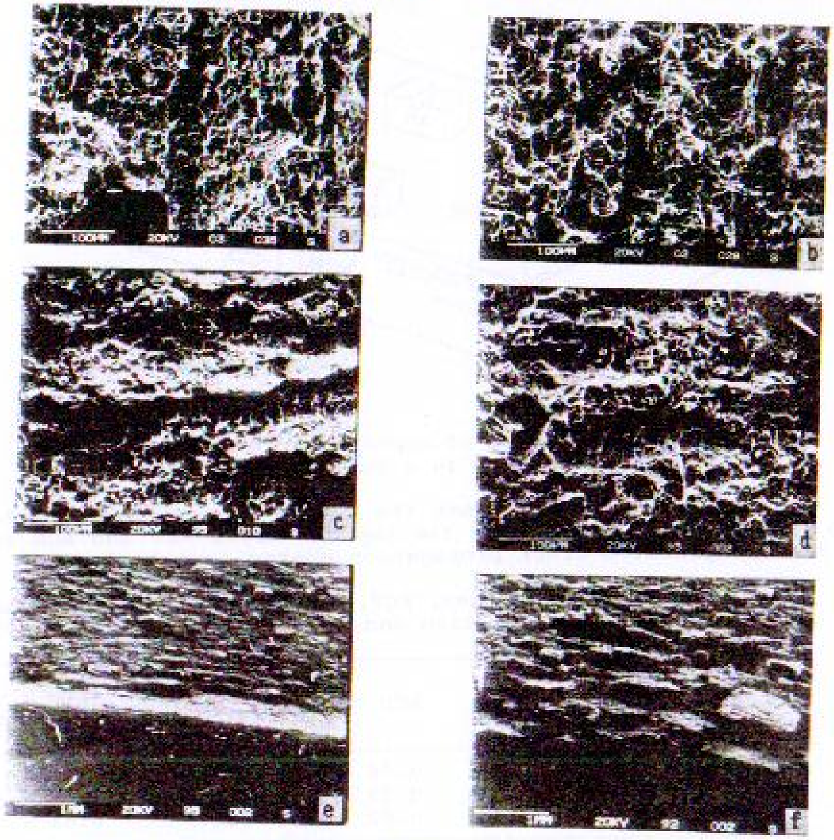

Fig.4. The characteristic photographs of a microsections of crack propagation zones on fracture surfaces of impact specimens of ПД(a), ПВ(b), ВД(c), ВП(d), ДП(e), ДВ(f) types.

Fig.4.a. The crack initiation in these specimens was preceded by an appreciable plastic deformation along an intersecting under 90 degree {0001} and {10$\bar{1}$0} planes in <11$\bar{2}$0> direction which is in line with a direction of an applied load. Because of this the crack initiation energy is large (KCU init.= 0.33 Mj/m^2). Vertical specimens of ВП type (KCU prop.= 0.41 Mj/m^2), the tested section of which was taken out of an axial section of the billets indicate a contribution of the crystallographic texture only, as the structural texture of the material does not exist

in the axial layers. The direction of the propagation of the main crack was in line with the <0001> crystallographic orientation (fig.3.b) and traces of plastic deformation process by microtwinning mechanism were observed on the fracture surfaces of the specimens of this type, (fig.4.c.) The contribution of the both factors was investigated on the specimens of ПВ type (KCU prop.= 0.86 Mj/m^2). The impact values of these specimens was good related to the total values of impact, energies of the specimens of ПД and ВП type. In the specimens of ПВ type with the main crack propagation the energy was consumed either by a crack opening along the boundaries of the structurally pronounced fields or by a drastic change of its movement direction along the crystallographic axes of <0001> type normal to a front of the crack propagation (fig.3.c). Some jogs were observed on the fracture surfaces which is a feature of the crack propagation with large energy consumption (fig.4.g). However, the crack initiation energy of the specimens of this type was minimum (KCU init.= 0.06 Mj/m^2), as the direction of the operating load was not in the line with either sliding system, and the fracture preceded plastic deformation was not present.

The similar arguments can be put forward for the specimens of ДП, ВД, ДВ type. At the time of their fracture the main crack meets the structurally and crystallographically pronounced fields oriented across the rolling direction. As the component is not base one (about 20%), its embrittlement effect was smaller, and impact values was higher as compared to the corresponding samples of ПД, ВП, ПВ type (see Table 1). A fractographic analysis of the fracture surfaces of the specimens. Fig.4.b,d,f showed, that they fractured by the similar mechanisms, fig.3.a-c

Thus we can summarize that in the investigated billets after hot deformation a strong structural (in the surface layers) and crystallographic (across the full plate thickness) texture of material with lamellar structure is generated. These layers of the basic orientation of interface boundaries of the structurally and crystallographically pronounced fields of 20-30 μm in width are regularly distributed across the full thickness of the billet and spaced by 100-170 μm. The existence of this fields in the material results in a change of a fracture mechanism and in an enhancement of the anisotropy of impact values of the specimens in the two-phase titanium alloys.

LOW CYCLE TESTS

A similar combination of the investigations was carried out on a low cycle specimens with a circumferential notch taken out of the surface layer of a billet in such a manner as it axis was parallel to the rolling direction, fig.5.a. 120 specimens tested in a 3% NaCL solution in a regime of a form zero tension under pulsed cycle loading of 2-3 c/min and of applied stress amplitude 0.8 and 0.7 of the average value of the yield strength. Cycles to fracture change in 200-1900 and 700- 3800 range. Thus with a reduction of applied stress value the scatter of cycles number to fracture increases.

A fractographic analyses of macro- and micro topography of the specimens allow to assume that with an increase of the main crack length and a reduction of the gauge section of the specimen four characteristic fracture zones. The zone of the fatigue crack initiation (zone 1) changed for a zone of stable crack propagation of large fields of regulary fatigue strations (zone 2). Then a field of an accelerated crack growth followed, where fatigue fracture mechanism was added by a mechanism of a single quasi static failure (zone 3). And, finally, the field of an after fracture appropriate to a fact static fracture of a final part of the specimen (zone 4). The micrographs of the zone 3, the zone of the accelerated crack growth represented the mosaic of the misoriented shear facets and microstriction colonies normal to them. This field can be designate a corrosion embrittlement zone (fig.5.b) as on the fracture surfaces of the specimens fractured in an air inspite of the existence of microstriction, share facets were not ofserved.

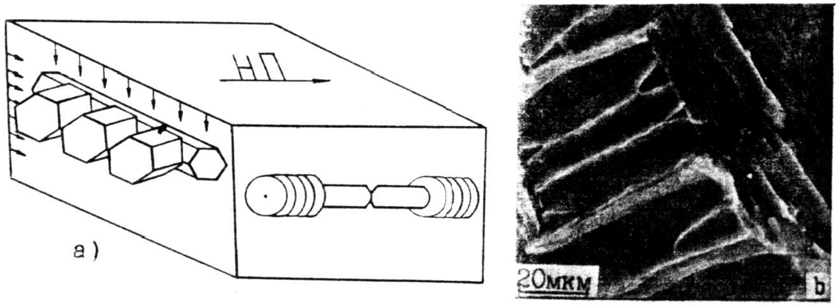

Fig.5. The fracture scheme (a) and a characteristic appearance of the fracture surface (b) of low cycle specimens after sea water tests.

The zone of corrosion embrittlement was of great area on the fracture surfaces of the samples of low number of cycles to failure and came out on the edge of the sample. The color electrochemical painting of the metal just before the failure aligns to defect the structurally and crystallographically pronounced fields of the basic orientation of the interface boundary at the places of the corrosion embrittlement either does not exist on the fracture surfaces of the samples of high number of cycles to failure or there was in the middle portion of the fracture surface. The colour electrochemical painting of these sample detected a non-existence of the elongated α-phase particles of the basic orientation of the interface boundaries in the plane of the main crack propagation.

The above discussed combination of the investigation allowed to understand the fracture mechanisms of the low cycle longitudinal samples of structurally and crystallographically pronounced fields oriented across the rolling direction (fig.5.a). As the samples were notched circumferentially, the zone of the main crack initiation was potentially over the whole sample perimeter at the same time. However, as it had been shown recently, in places, where structurally and crystallographically pronounced fields randomly occured in the crack initiation zone, and were oriented in such a way that the direction of the active load was not in line with either of plastic deformation system (for example, on the samples of ЛВ type, fig.3.c), the crack of the minimum energy of crack initiation lazily generated along plane base. Further tare place a drastic change of its movement direction along the crystallographic axis of <0001> type normal to a front of the crack propagation, and the same time opening its bye mechanism of multiple sliding along an intersecting crystallographic planes of $\{10\bar{1}0\}$ type to the $\langle 11\bar{2}0\rangle$ direction. The shear facets with microstriction colonies normal to them appeared on the fracture surfaces (fig.5.b) which is in agreement with the Wanhill (1976) suppositions relating to the Ti-6Al-4V alloy.

CONCLUSION

Thus, the structurally and crystallographically pronounced fields of the base orientation of the interface boundaries 20-30 µm in width spaces across the thickness of the hot rolled billet by 100-170 µm is shown to be responsible for the enhancement of anisotropy of impact values, the increase of the scatter of the low cycle test results of the specimens in the two-phase titanium alloys. The lower the applied stress value at the time of the specimen testing (impact or cyclic), the more the contribution of crack initiation period in its life time, the more important is the account of the number and geometry of the location in a bulk of the flat billets of such structurally and crystallographically pronounced fields effecting on the fracture mechanism change of the tested samples.

REFERENCES

1. Kolachev B.A., Malkov A.V. (1983). The physical base of the titanium fracture, Metallurgia, Moscow.
2. Wanhill R.J.H. (1976). A Fractographic Analysis of Environmental Fatique Crack Propagation in Ti-6Al-4V sheet. Corrosion, v.32, May, p.162-172.