METALLURGICAL AND TECHNOLOGICAL ASPECTS OF BRITTLE BEHAVIOUR OF TITANIUM ALLOYS

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ABSTRACT

Embrittlement of high strength titanium alloys may be stipulated both by some aspects of material's nature and by defects. Defects causing local embrittlement and premature fracture of titanium alloys of ingot metallurgy are accounted for "smithed-in" surface layers of high gas concentration during fabrication of details. In alloys of granule metallurgy analogous defects are caused by granules of other alloys or nonmetalic inclusions. The sizes of diffusional zones around all sorts of impurities are the important factor~~s~~ from fracture mechanic's point of view.

KEYWORDS

Alloy, embrittlement, fracture, defects, quasicleavage.

INTRODUCTION

High strength titanium alloys are extensively used as constructional materials in modern technics. With the UTS as high as 1100 MPa their elongation is approximately 5-8% .As a rule relief of fracture surfaces of tested specimens and different details produced out of such alloys is dimpled, characteristic for ductile failure. But sometimes in exploitation and miscelaneous technological testing occurs brittle fracture.There are two approaches to the definition of brittleness: 1) according with caracteristics of plasticity or toughness; 2) according to reliefs of fracture surfaces. The latter allows to elucidate the cause and sometimes even the mechanism of embrittlement.

Research results of the nature of premature failures show that their genuine cause is often closely connected with the defects of the metal. The determination of the stage of metallurgical and technological history of given semiproducts or hardware where defects appeare in many cases is possible by means of an electron microscopy and microanalysis.

The aim of our work has been the determination of embrittling factors stipulated both by the nature of alloys and by defects produced during fabrication processes, establishing of the found defects origin.

MATERIALS AND INVESTIGATION TECHNIQUES.

The specimens for the investigation have been cut out of forgings and castings of titanium alloys fabricated in compliance with departmental standards. Treatments of the alloys, characteristics of their structure and data relating to the beforehand fracture or embrittlement are given in table 1.

Table 1.Techology and criteria of premature fracture and brittleness.

Alloy Detail	Processing Treatment	Criteria of premature fracture or brittleness
BT23 sph.tank	I/M,HT:820^{0}+ 480 ^{0}5h;	0,6 *)
BT6C sph.tank	I/M,VA:750^{0}C	0,8 *)
BT3-1 cover	I/M,HT:930^{0}C+ 650^{0}C	0,8-0,5*)
BT5-1KT specimen	I/M,VA:800^{0}C 1h;.	KCU=0.5-1,4Kg/mm^{2}
BT14 specimen	I/M,HT:910^{0}C 1h+620^{0}C 2h;	———
BT14 specimen	I/M,HT:960^{0}C 1h+620^{0}C 2h;	GBFS
BT23 specimen	I/M,HT:800^{0}C 1h+525^{0}C 10h;	———
BT23 specimen	I/M,HT:960^{0}C 1h+525^{0}C 10h;	GBFS
BT5-1KT specimen	G/M,C:960^{0}C 12h 160MPa	elongation 0 - 7%

I/M or G/M is for ingot or granule metallurgy;
HT: the temperature and the time of solution treatment + thesame for ageing;
VA-vacuum ageing:temperature and time of treatment.
GBFS - grein boundari fracture surface.
*) - ratio of breaking to desing loads.

For the investigation of fracture surfaces, has been used scanning electron microscop Philips PSEM-500 with the attacthment for microanalysis EDAX-711. Microstructure of alloys has been studied by optical microscopy. Aforementioned specimens were both usually tested for determination of tensile or impact toughnes properties and piecies of materials with a fraction of big fracture surfaces. The sizes of latter were fit to mount them in specimen holder of PSEM-500. Usually they contained zones of fracture initiation (ZIF) and somtimes neighbour areas of its continuation. ZIFs have been determind by macroanalysis.

Specimens were cut off by mechaical mashining with a cooling by water emulsion. Before the investigation in SEM they had been cleaned ultrasonicaly in some water or ethyl alcohol solutions. Some model alloys produced by methods of granule metallurgy (G/M) were studied to account for the defects orign. To the granules of titanium alloy on prefabrication stage were added few particles of metalic or nonmetallic nature. In this case a temptrature and a time of every production stage are known. It gives the opportumty by a comparison of diffusional zones' sizes in real and model materials to make out more accurate some details of defects origin in former.

THE EXPERIMENTAL RESULTS.

As a rule the ZFIs were of different colour against the background of the main fracture surface. The probable cause of this phenomenon is the unequal reflective properties of observed fracture places. For example on the fracture surface of spherical tank out of alloy BT6, which failed prematurely at the individual test, the ZFI has a coarse faceted relief (Fig.1a). Almost flat facets of this relief are typicaly of quasicleavage charackter (Fig.1b).

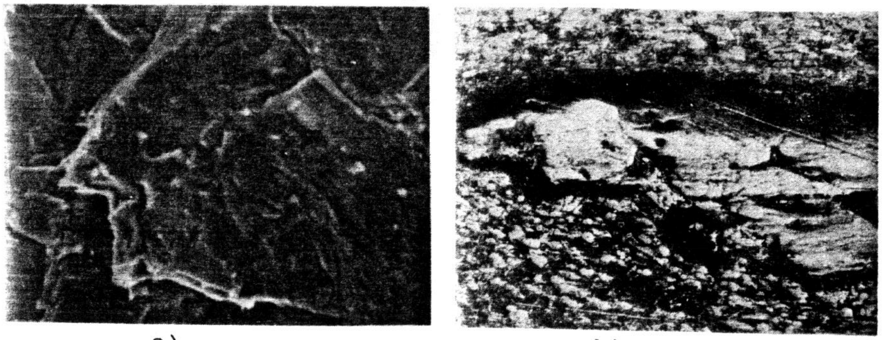
a) b)

Fig.1.Microfractograph (a) and the microstructure (b) in ZIF of spherical tank out of alloy BT6.

Additionaly there are many cleavage cracks in this zone. Microstructure here contains many light inclusions encircled by dark pores and ribbonlike constituent. Microanalysis data show that light inclusions has the same contents of aluminium and vanadin as the base alloy but the dark ribbonlike constituent contained as much as 20%V . The sizes of light inclusion and of cleavage facets on fracture surface are about equal. On the microphotography (Fig.1b) cracks begin at the inclusions and continue in base metal.

Defects of similar character have been found on fracture surfaces and in microstructure of prematurely failed during individual tests spherical tank and "cover" produced out of alloys BT23 and BT3-1 respectively. In ZFIs here also exist large quasicleavage facets and many cleavage cracks. The microstructure of metal adjacent to the ZFIs is formed of coarse plates and some areas appear as homogeneous α-phase. These features are characteristic for the layers with high concetrations of gaseous impurities. Indeed, the concentration of oxygen in the areas of the defects may reach up to 8-9%.

Next fact akin aforementioned failures is the case of low impact toughness in specimens out of alloy BT5-1КТ tested at -253°C . The relief of their fracture surfaces was formed out of dimples of different sizes (Fig.2a) and is almost normal for ductile fracture. But in the some areas of surfaces have been detected increased concentrations of silicon, iron (Fig.2b) and tin.

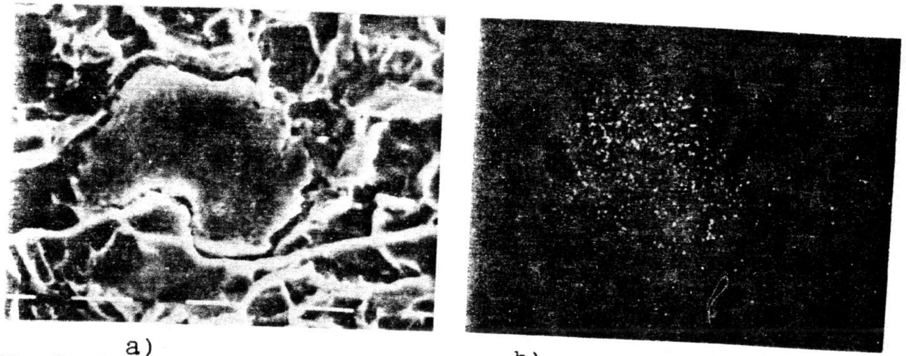
a) b)

Fig.2. The microfractograph (a) and Fe K_{α} X-ray image (b) of the same place of specimen out of alloy BT5-1KT.

Microstructure of the metal, adjacent to the fracture surfaces, contained inclusions of an iron rich phase along grain boundaries. The mean diameter of the inclusions is about 1μ.

An alternative to presented afore premature failures is one which happened at the tecnological test of forged flange out of alloy BT3-1. Investigtion in SEM in ZFI have been found dimpled relief but with elongated dimples. On polished section square to the fracture surface after etching was seen light stuctural constituent (Fig.3) of 45mm length. Accoding to the microanalisys data it was very low alloyed (~98% Ti, ~1% Al).

Its microhardness value was only 273 kpd/mm^2 whereas the same characteristic of base alloy was 360 kpd/mm^2. The latter corresponds to the property of heat treated alloy BT3-1. In this case the light phase happend to be soft α-phase. Until now have been scrutinized alloys produced by usual ingot metallyrgy (I/M). Further are presented results obtained for alloys fabricated by granule metallurgy .

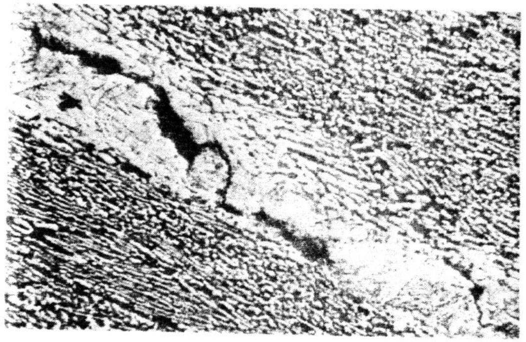
Fig.3.The microstructure of the alloy BT3-1 in ZIF of the detail "flange".

On the fracture surfaces of specimens of embrittled G/M alloys were met defects which look out like a particles or their imprints on the inspected surfaces. This is true both for model and commercial G/M alloys. The particles'imprints are encirculed with areas of quasiclivage appearence (Fig.4a). The real inclusions were of different nature: SiO_2, CaO, Fe, Ni, Cu or granules of another titanium alloy. In quasiclevage areas by microanalisys always were discovered elements contained in the inclusions (Fig.4b). Hence the size of quasiclevage area in

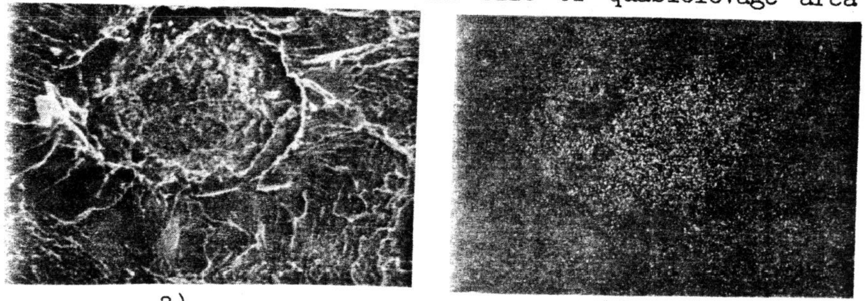
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Fig.4.The microfractograph (a) and NiK_{α} X-ray image (b) out of G/M BT5-1KT alloy.

each case may be admitted as a measure for diffusional zone's length.

If not admittedly, inclusions get in commercial alloys at different stages of production but always at solid state of granules or their compacts. Diffusion of constituent elements in titanium alloy take place during hot working and heat treatument. High concentrations of such elements within diffusional zone stipulate embrittlement of alloys and premature failures of specimens and machine parts.

Yet another aspect of brittle and in a sense premature failure occurs in creep tests. If (α+β)- alloys are quenched from β-region they acquire coarse grained Widmanstedt microstructure (Fig.5a). After proper ageing the alloys achieve the high strength. In our work has been investigated creep behaviour of (α+β) alloys BT14 and BT23 at room temperature. The alloys were quenched from 950°C(β-region) or from (α+β) region (910°C-BT14; 800°C-BT23) in cold water and then aged: former-at 620°C,2h; latter - at 525°C,10h.

Specimens of alloys quenched from high temperature and aged showed at constant stresses near yield stress very low creep rate and failed after very small elongation. In macroscale the fracture surfaces were approximately perpendicular to the tensile stress. They were formed of rather big quasiclevage facetes going along grain boundaries (Fig.5b). The same is true for specimens tested after some sustained loading in tension mode till a rupture.

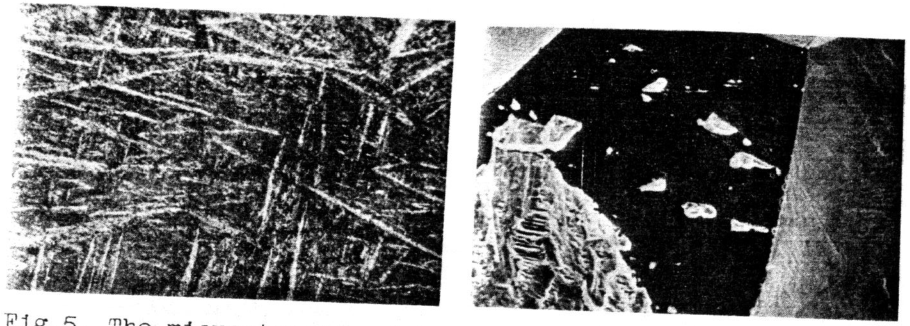
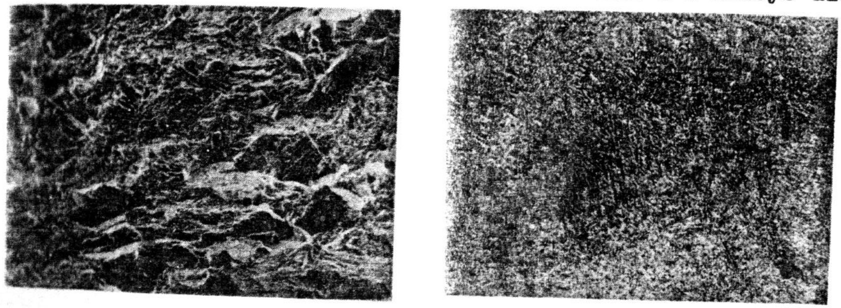


Fig.5. The microstructure (a) and microfractograph of the specimen out of alloy BT23 (HT:960°C, 1h + 525°C, 10h) ruptured after creep test.

The opposite effects were demonstrated by specimens aged after low temperature quenching.The creep rate in these cases was rather high and the creep deformation of specimens at the time of a failure was approximately equal to the elongation fixed in tensile tests of specimens in the same conditions. The fracture surfacaes of these specimens were also faceted but the

transkristalline (Fig.6a) and oriented at about 45° to the tensile axis. The microstructure of the specimens was of basket weave type (Fig.6b).

The nature of the defects - how they look on the fracture surfaces and what is the chemical contents in particles and their adjacent areas in model and commercial G/M alloys allowed eazily to find out the ways by which different impurities have



a) b)

Fig.6.The microfractograph (a) and the microstructure (b) of the specimen out of alloy BT23 (HT:800°C 1h +525°C 10h).

THE DISCUSSION OF RESULTS.

got in the alloys. For example, inclusions of SiO_2 and CaO did so from dust of work places, metallic inclusions are from the rest of granules of other alloys on package walls and on instruments needed to manipulate with granules and their compacts.

In I/M alloys defects may appear both during smelting and processing, especially by rolling and forging. Typically metallurgical defect is one in flange out of BT3-I. Because of poor mixing of raw materials in a charge there was not achieved uniform distribution of the alloy's components in primary ingot and following heats at all stages of processing. Just in this case preserved large area of the almost unalloyed titanium with the ultimate stress mach less than the rest of the alloy has. The case may be called ductile "embrittlment" inasmuch such characteristic as a rupture stress is much lower then admissible one but all microstructural features of the fracture surface are essentialy ductile. The defects of the sort are encoutered rather offen (Borisova et al,1980).

The brittleness of such items as spherical tanks out of alloys BT6 and BT3-I and "cover" out of alloy BT3-I is real one. The defects here are of the type caused by intrusion of surface oxide film in inner parts of a metal during its hot working. The prooves of the such their nature are in that that areas of high oxigen content or α-phase of high hardness is in close neighbourhood with areas enriched with V,Si,Fe,Sn or Al. These elements usually segregate either in the oxide film (Al) or beneath of it (V,Sn,Fe, etcetera) (Korolev et al,1964) The areas of homogene α-phase or of high its content appeared due to diffusion of oxigen from oxides into a metal. The sizes of corresponding diffusional zones as they appear on fracture surfaces (Fig.5a) or in microstucture (Fig.5b) are by the order of magnitude the same as in model alloys produced by G/M methods. The latter is in a consent with formation of defects in a solid state condition of a metal.

The brittlness assotiated wiht defects is connected with the fundamenttal properties of alloys only indirectly. For example, due to high solubility of oxigen in titanium realises saturation of metal adjacent to "smithed-in" particles of oxide films by this gas. But behaviour in creep conditions is more straight connected with the nature of alloys. Thus the brittle failure of aged specimens after quenching from β-region caused by grain boundary embrittlement when grains are of big size is inherent for titanium alloys. The meaning of this notion is in that the same behaviuor may by encountered in metal of heat affected zones of weldments.

It must be noted that the sizes of defects or more accurately of their diffusional zones and the rupture stresses for the given specimen are the data for accounts of fracture michanics characteristics of materials.

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