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PRODUCTION OF AIRCRAFT ENGINE COMPRESSOR ROTOR DISCS WITH DESIRED SERVICE LIFE IN TITANIUM ALLOYS

A.G. Ermatchenko, R.M. Kashaev*

Institute for Metals Superplasticity Problems of RAS,

Khalturin str. 39, Ufa 450001, Russia

**e-mail: rishat@kashaev.ru*

Abstract. We consider the problem of optimizing technological regimes of forging aircraft engine compressor rotor discs in high-temperature titanium alloys under conditions of superplastic deformation and suggest a solution to it. We characterize the technological possibilities of producing forged disc billets with a desired structure that provides the formation of a required set of mechanical properties. A general scheme of the technological solution to the problem and of the provision of a required service life in high-temperature two-phase titanium alloys is provided. We present the results of structure studies, investigations of mechanical and service properties of compressor discs with different types of microstructure (globular, bimodal, and lamellar), that are produced in articles during severe plastic deformation under superplasticity conditions.

1. Itroduction

The requirements to the state-of-the-art of machinery and equipment become more and more severe. That is why the challenge of guaranteeing and increasing service life of materials is of primary importance.

A number of the earlier published works have shown how fundamental investigations of superplastic deformation phenomenon have been used to develop and master the application of efficient resource-saving technologies to the serial production of near-net shape forged billets out of commercial titanium alloys. New technologies provide: savings in material consumption by 2-5 times, reduction in machining cost by 20-30 %, the produced articles being of higher quality. This is illustrated in Fig. 1, where one can see the near-net shape forgings of compressor rotor blades of gas turbine engines (GTE) produced from high-temperature titanium alloys [1, 2].

Fig. 1. GTE compressor rotor blade forgings.

The aim of this paper is to consider the advanced technology for producing compressor disc forged billets with desired properties using superplastic deformation regime. And show that it will provide significant savings in material consumption and increased service life of aircraft engines.

First experimental works on the subject "Deformation processing in superplasticity regime – production of aircraft engine compressor discs out of titanium alloys" were performed by IMSP scientists in cooperation with Indian colleagues at Defence Metallurgical Research Laboratory (DMRL). Indian enterprises: DMRL, Mishra Dhatu Nigam (MIDHANI) and Hindustan Aeronautics (HAL) had a program on the development of compressor discs, 350-400 mm in diameter, in a near-α titanium alloy LT26A (equivalent to IMI-685) for a jet engine. The alloy IMI-685 (Ti-6Al-5Zr-0.5Mo-0.25Si) was designed for applications in aeroengines up to a temperature of 520 °C. The results of mechanical tests of the specimens cut from discs are presented in Tables 1 and 2 [3].

Table 1. Chemical composition and mechanical properties of as-received titanium alloy LT26A.

Chemical composition (wt, %)									
Al	Zr	Mo	Si	Fe	C	O_2	N_2	H_2	Ti
6.17	5.9	0.53	0.26	0.024	0.041	0.145	0.0017	0.003	balance

Tensile properties	Ambient	520 °C	Creep properties: Test parameters	Total plastic strain (%)
0.2% PS (MPa)	963	559	520 °C/310 MPa for 100 h	0.075
UTS (MPa)	1046	681		
EI (%)	11	13		
RA (%)	22	43		
Notched strength (MPa)	1618			
N/P ratio	1.55			

Table 2. Mechanical properties obtained on isothermally forged discs.

	IMI-685 disc		Forged LT26A discs	
Tensile properties	RT	520 °C	RT	520 °C
0.2 % PS (MPa)	910	530	959	534
UTS (MPa)	1027	681	1034	677
EI (%)	11	18	9	16
RA (%)	21	49	16	43
Notched strength (MPa)	1649		1572	
N/P ratio	1.61		1.52	
Creen strain data (%) (520 °C; 310 MPa; 100 h)	0.04; 0.02; 0.05		0.1; 0.14; 0.1	
Post creep tensile data	RT		RT	
0.2 % PS (MPa)	951		996	
UTS (MPa)	1017		1043	
EI (%)	11		7	
RA (%)	19		12	
LCF, cycles to failure (0.1P-1.0P; 10-20-10-20 s cycle; RT)	2794; 2830; 4957; 2943		4918; 2109; 2357; 3712	
Fracture toughness, K_{1c} (MPa √m)			61; 65; 63; 69	

The material science approach to the solution to the problem of producing a desired structure that provides the formation of a required set of properties in aircraft engine compressor rotor discs is based on numerous investigations of the interrelation between structure constitution and mechanical properties of two-phase high-temperature titanium alloys [4-7].

From all the different types of microstructures produced in two-phase titanium alloys during thermomechanical processing, the most important ones for generating the required properties are the following: 1) an equiaxed (α+β) structure - optimum for parts experiencing considerable alternating loads during operation, such as compressor rotor blades; 2) a bimodal structure – for a wide range of parts operating under different temperature and loading conditions; and 3) a lamellar structure, forming extra high-temperature properties with satisfactory plasticity - optimum for compressor rotor discs [8, 9].

It should be noted that conventional methods of hot processing on crank presses do not provide the uniform temperature and deformation fields throughout a whole billet in full measure. That is why structure non-uniformity occurs in deformed semi-products. This in turn results in the anisotropy of material's properties, and, consequently, in the decrease of article's quality. Most noticeably it is revealed in manufacturing of large size parts, particularly, GTE discs. If we take into account that discs are critical parts for aircraft engines, the challenge of guaranteeing the required set of mechanical properties throughout such parts is of particular importance.

In this work, a fabrication route involving severe plastic deformation under superplasticity regime was used for producing the required properties in large size forged discs out of two-phase titanium alloys. Table 3 presents a standard fabrication route of producing discs, 400 mm in diameter and 60-70 mm in height [10].

Table 3. A standard fabrication route of producing discs.

No	Processing stage	Method to obtain the result
1	Generating uniform structure of a certain (desired) type	Deformation in superplasticity regime: multiple forging with differential rotations of a starting cylindrical billet
2	Obtaining article's shape	Deformation in temperature – strain rate superplasticity regime regulating metal flow
3	Producing required properties	Thermal treatment and thermomechanical processing depending on operating conditions

2. Experimental

In this study we use a hot-rolled turned rod, 190 mm in diameter, in the high-temperature two-phase titanium alloy VT9 (Ti; 6.25 % Al; 3.5 % Mo; 1.7 % Zr; 0.25 % Si). The microstructure of the starting rod transformed β-grains of an average size of β-phase (about 300 μm) with a pronounced decoration of α-phase (Fig. 2).

Discs were deformed on a 16 MH hydraulic press using isothermal conditions in the temperature-strain rate regime: T = 950 °C; strain rate 10^{-1} – 10^{-3} s^{-1}, according to the route given in Table 3. After deformation, the forged discs were subjected to heat treatment according to the following regime: heating up to T=950 °C, soaking for 2 hours, cooling in the air, followed by heating up to T = 530 °C, soaking for 6 hours and cooling in the air.

The macrostructure was evaluated using macro-templates sliced in the axial direction of the forged billets. The microstructure was evaluated using micro-sections in three orthogonally related directions. Microstructure analysis was carried out using a Neophot-32 light microscope with magnification x 500. Average grain sizes were calculated using the size of α-particles for the globular structure and the size of β-transformed grains for the lamellar structure. Specimens for mechanical tests were cut from the central and peripheral zones of forgings in radial and tangential directions. The isotropy of mechanical characteristics was evaluated using anisotropy factor $K_a = X_t/X_r$, where X_t and X_r are the values of characteristics obtained during testing of tangential and radial specimens, respectively.

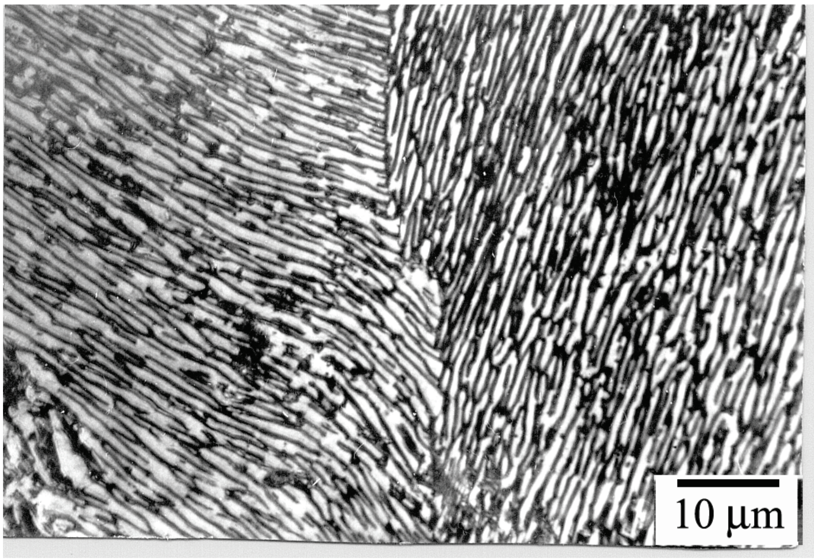

Fig. 2. Microstructure of starting rod.

3. Results

Mechanical properties at room and operating temperatures are shown in Tables 4 and 5.

Table 4. Mechanical properties after upsetting.

Control point in a disc	UTS, MPa	El, %	RA, %	Impact toughness, U-notch MJ/m²
Tests at 20 °C				
Base	975 / 990	8 / 11	22 / 25	0,47 / 0,51
Center	1060 / 1100	10 / 15	28 / 36	0,40 / 0,47
S	8,52	1,93	2,20	0,314
Ka	1,02	1,45	1,24	1,16

Note: 1. Mean values of mechanical properties of VT9 alloy specimens cut in radial direction are given in the numerator, in the denominator - mean values of mechanical properties of VT9 alloy specimens cut in tangential direction, after upsetting and annealing. 2. S - standard deviation of mechanical property values.

Table 5. Mechanical properties after severe plastic deformation.

Control point in a disc	UTS, MPa	El, %	RA, %	Impact toughness, U-notch MJ/m²
Tests at 20 °C				
Base	1010/1015	15/16	37/39	0,43/0,44
Center	1015/1020	16/16	36/39	0,44/0,44
S	5,16	1,21	1,41	0,113
K_a	1,01	1,01	1,02	1,13
Tests at 500 °C				
Base	745/750	24/25	55/55	-
Center	750/755	25/26	53/55	-
S	3,87	1,3	1,41	-
K_a	1,01	1,01	1,02	-

Note: 1. Mean values of mechanical properties of VT9 alloy specimens cut in radial direction are given in the numerator, in the denominator - mean values of mechanical properties of VT9 alloy specimens cut in tangential direction, after severe plastic deformation and annealing. 2. S -standard deviation of mechanical property values.

The test results show that the level of mechanical properties after processing involving severe plastic deformation route is significantly higher and more uniform than after upsetting.

It should be noted that a uniform structure generated throughout a whole disc makes it possible to carry out forging in the superplasticity regime with the desired structure (bimodal, lamellar), that provides increased compressor service life in whole.

Figures 3 and 4 show the results of testing of the set of disc's mechanical properties with bimodal and lamellar structures at room and operating temperatures. Figure 5 shows the microstructure after various processing modes.

The results obtained during the mechanical tests are in good agreement with structural changes in discs. The macrostructure in disc's section after upsetting has two anomalous zones: 1) a zone of intensive plastic flow, and 2) a zone of hindered deformation. The macrostructure is matte and grainless in the zone of intensive flow, while the grains are coarse, recrystallized and heritable from the starting billet in the zone of hindered deformation. The macrostructure after severe deformation is matte, uniform and practically grainless throughout the cross section.

We compared the results of mechanical tests and metallographic examinations to show the dependence of the uniformity of alloy's mechanical properties on the uniformity of microstructure produced during deformation.

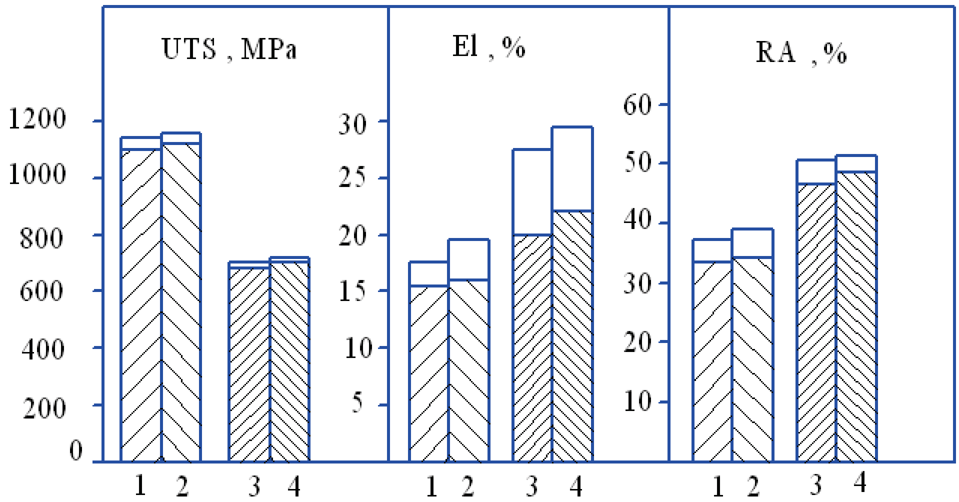

Fig. 3. Mechanical properties of disc with bimodal structure.

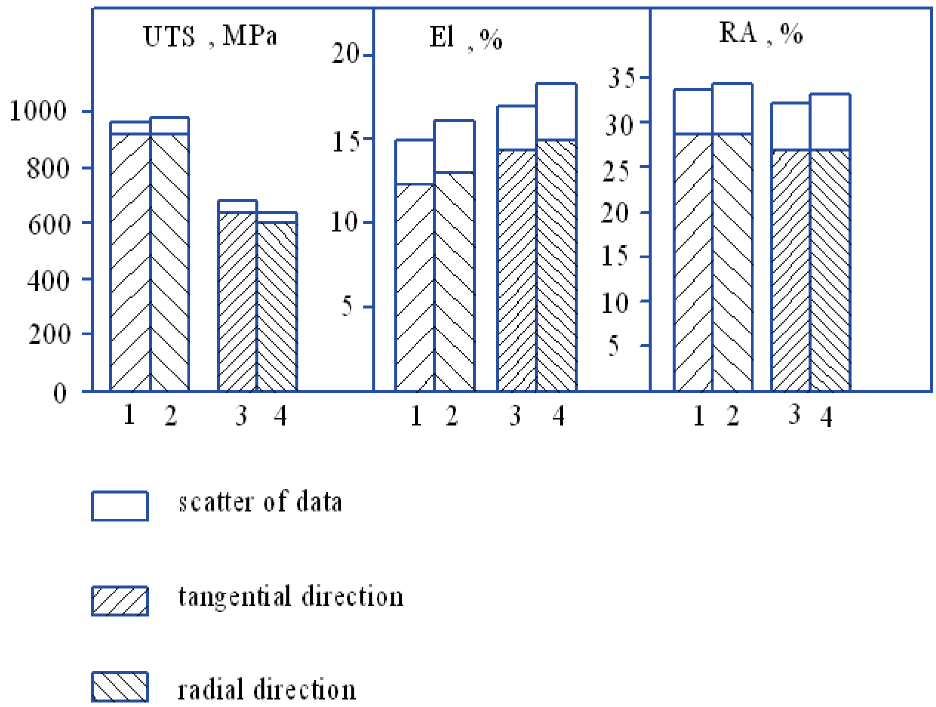

Fig. 4. Mechanical properties of disc with lamellar structure.
1, 2 – testing temperature 20 °C; 3, 4 - testing temperature 500 °C.

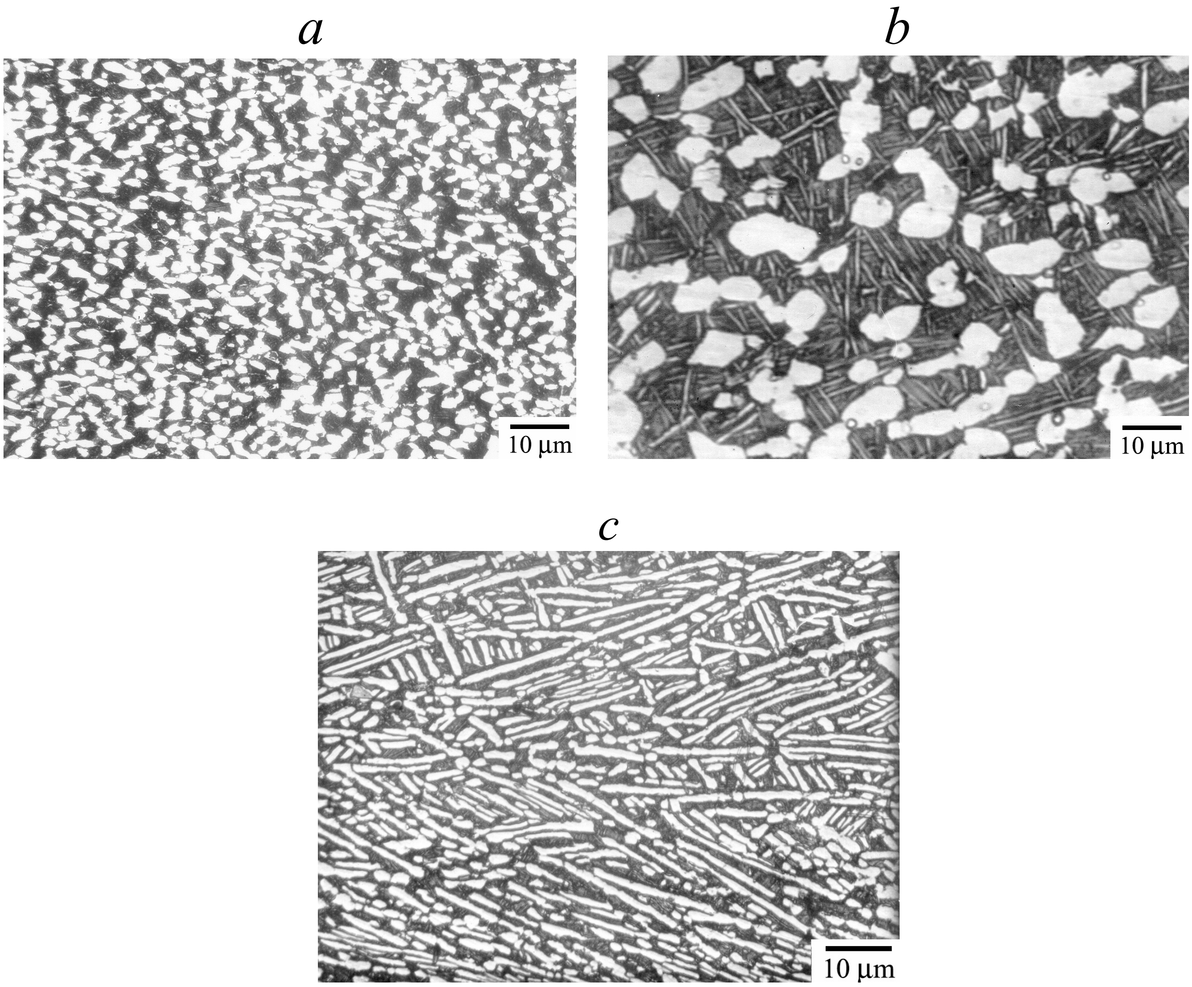

Fig. 5. Microstructure of VT9 alloy after different processing routes: a) globular two-phase, optimum for compressor blades; b) bimodal, optimum for any compressor parts; c) lamellar, optimum for compressor discs.

4. Conclusions

The problem of producing discs in two-phase high-temperature titanium alloys with desired mechanical properties is treated as the challenge of producing a certain type of microstructure.

It is shown that severe plastic deformation in superplastic deformation regime provides the formation of a sufficiently uniform structure of different types depending on regimes of thermomechanical processing and thermal treatment.

The results obtained show that severe plastic deformation in superplasticity regime and subsequent regimes of thermal treatment allow to produce critical parts (discs) with desired service life from titanium alloys.

References

[1] A.G. Ermachenko, M.V. Karavayeva, J. Mater. Eng. Perform. 5 (1996) 589-592.

[2] A.G. Ermachenko, A.A. Zaripov, M.A. Semakov, In: *Proceedings of International Conference Current Status of Theory and Practice of Superplasticity in Materials* (Gilem Publ., Ufa, 2000) p. 302.

[3] M.C. Somani, R. Sundaresan, O.A. Kaibyshev, A.G. Ermatchenko // *Mater. Sci. Eng. A* **243** (1998) 134.

[4] O.P. Solonina, S.G. Glazunov, *Ti Superalloys* (Metallurgia, Moscow, 1976).

[5] E.A. Borisova, G.A. Bochvar, M.Ya. Brun, *Metallography of Titanium Alloys* (Metallurgia, Moscow, 1980).
[6] E.W. Collins, *The Physical Metallurgy of Titanium Alloys* (ASM, Metals Park, OH, 1984).
[7] O.A. Kaibyshev, *Superplasticity of Commercial Alloys* (Metallurgia, Moscow, 1984).
[8] U. Zwicker, *Titan und Titanlegierungen* (Springer-Verlag, Berlin, New York, 1974).
[9] D. F. Neal, In: *Forging and Properties of Aerospace Materials* (The Metals Society, Chameleon Press, London, 1978) p. 199.
[10] A.G. Ermachenko, M.V. Karavayeva // *Physical Metallurgy and Heat Treatment of Metals* **2** (1999) 36.