CHANGES IN STRUCTURE OF TWO-PHASE TITANIUM ALLOYS IN FORGING

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Abstract. In recent years, the extent of application of titanium alloys in industry has been continuously increasing. Because of their high specific strength, creep resistance, corrosion resistance in a number of active media, as well as the favourable strength to specific ratio, the titanium alloys have gradually acquired a signification position in a number of industries, starting with the food industry, through engineering, health application, up to aviation and space industry. In this paper the results of extensive research into the aspect of application of Ti alloys in manufacturing components of an aircraft engine are presented. The experiments were carried out on two types of Ti alloys. The most demanding area in the structural analysis is the examination of processing failures, determination of their reasons, and preparation of measures aimed at preventing these failures. The aim of this paper was to determine the processing condition for two alloys in all operating sections to optimise the structural parameters in order to obtain the required mechanical properties.

Keywords: structure, two-phase titanium alloys, forging.

Introduction

In recent years, the extent of application of titanium alloys in industry has been continuously increasing. Because of their high specific strength, creep resistance, corrosion resistance in a number of active media, as well as the favourable strength to specific ratio, the titanium alloys have gradually acquired a signification position in a number of industries, starting with the food industry, through engineering, health application, up to aviation and space industry.

These alloys are divided according to the structure of the alloys α, pseudo α, α + β, β and pseudo β alloys. The alloys have good strength and resistance to brittle fracture even at very low temperatures. In addition to aluminium, which stabilizes the phase α, they contain neutrally applied tin and zirconium. The adverse properties of alloys α are limited ductility when cold. Representative is TiAl5Sn2.5 [1-4]. Pseudo α alloys: in the basic phase of Ti - Al elements are added stabilizing and reinforcing the phase β. Further hardening is achieved by active Zr and Sn. The content of β phase is 2-6 wt. %. These alloys have strength of 10 to 20% higher than alloys α [4; 5]. Adding a small amount of elements, which stabilize the β-phase, pseudo alloys α incur. These are alloys containing from 2 to 8 % of β phase. The basis of these alloys is TiAlMn(V) [6].

Alloys α + β are characterized by a wide range of structures and properties. They may be formed either as equiaxed grains or lamellas of both solid solutions, or mixtures of both morphologies [3-5]. The content of β-phase in these alloys according to the type and contents of alloying elements is from 5 to 50 %. If the alloy contains to 25 % β – the phase belongs to the group of martensitic alloys, with rapid cooling from the β-phase the martensitic phase α' and α'' occurs. When the β-phase content is greater than 25 %, we can keep it during the cooling in the structure of phase β, but it is usually transferred to the phase ω (transitional phase with a hexagonal lattice). These alloys are called alloys with metastable (transient) β-phase [7; 8]. Among the alloy α + β martensitic type the alloy Ti-6Al-4V is best known [1].

Alloys β have a content of alloying elements in excess of 20 %. They often have a small content in the structure of α phase and are usually alloyed Fe, Cr, Mo, V, or their combinations. Examples of these alloys can be the binary alloy TiMo15 or alloy TiV10Fe2Al3 [5; 7; 8].

Pseudo β alloys have the content β stabilizers approximately 18 %, of which about 2 % is Fe and Cr, which creates an intermetallic phase. The content of Al is kept at 3 %. [5]. By increasing of the content β phase stabilizing elements and reducing the Al content (up to 3 %), there will be created metastable respectively pseudo-β alloys. The content of the β-phase depends on the temperature of heating and the cooling conditions. The grain size has great influence on the heat treatment [7-12].

The experiments were carried out on two types of Ti alloys. The most demanding area in the structural analysis is the examination of the processing failures, determination of their reasons, and preparation of measures aimed at preventing these failures. The aim of this paper was to determine the

processing condition for two alloys in all operating sections to optimise the structural parameters in order to obtain the required mechanical properties.

Materials and methods

Forgings of two different alloys were produced in the form of bars, 80 mm in diameter. The chemical analysis of these initial products was carried out with an ARL 35201CP spectrometer. The N_2 and H_2 content was determined in a LECO TC236 system. The results of the chemical analysis are given in Table 1.

Table 1

Chemical composition (wait %)

Alloy	Ti	Al	Mn	Mo	Cr	Si	Fe	N	H
1	Base	1.68	1.18	-	-	-	-	0.05	0.012
2	Base	6.24	-	2.37	1.89	0.33	0.59	0.05	0.015

Temperature ranges of forging in drop hammer are given for both alloys in Table 2.

Table 2

Temperature ranges of forging

Alloy	Temperature to which alloys were heated, ºC	Finishing forging temperature, ºC
1	900-940	750
2	950-970	850

On the basis of the experiments and the structural analysis which will be described later it will be possible to determine the thermal conditions of heating the alloys prior to forging and also determine the forging temperature for both alloys. The microstructure was analysed in a MeF3 microscope (Reichert) and SEM in a JSM 35 CF (JEOL). Etching of the specimens was carried out in the solution of the following composition: 10 ml H_2SO_4, 20 ml HF, and 14 g. of urotropin, the volume was then increased to 250 ml by distilled water.

Structural analyses

Alloy 1. It is pseudo α alloy. The structure at the lower beginning forging temperature (temperature to which the alloy was heated 900-920 ºC) shows a small number of secondary recrystallized grains. The β phase is mainly spheroidised and copies the form of initial lamellae of the β phase, Fig. 1.

Microstructure with a larger grain size corresponds to No. 6 and 7 according to ASTM. At higher forging temperature (930-940 ºC) the structure consists of a highly directional β phase which is mainly spheroidised, with fine recrystallized grains of the α phase, Fig. 2.
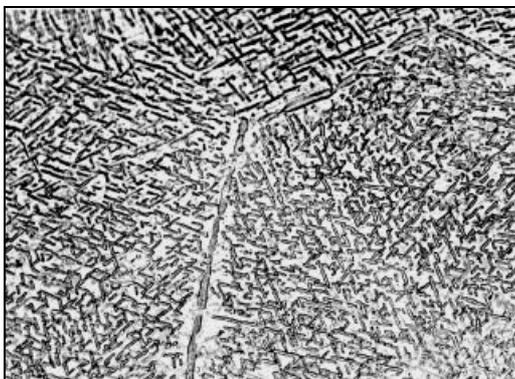

Fig. 1. **Longitudinal section**, mag. 500x   Fig. 2. **Longitudinal section, mag. 500x**
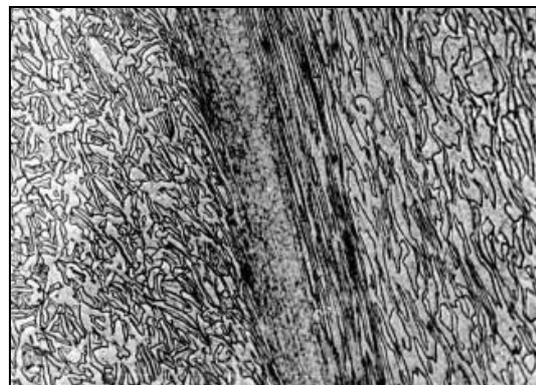
The grain size according to the forging temperature is given in Table 3.

Table 3

Grain size according to forging temperature

Forging temperature, ºC	Grain size according to ASTM
900	6
910	7
920	7
930	8
940	9

A part of the microstructure of the coarse-grained region visible by EM is given in Fig. 3.
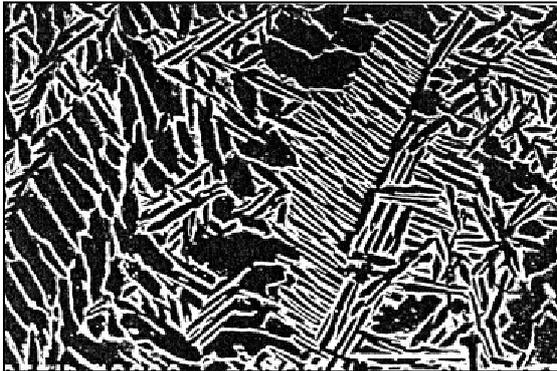
Fig. 3. **Coarse-grained region, EM, mag. 2.000x**

Fig.4 **Longitudinal section, mag. 500x**

Alloy 2. It is an α + β martensitic type alloy. The structure varies greatly depending on the forging temperature. At lower forging temperature (950, ºC) the structure consists of the lamellar α + β phase with the primary α phase at the boundaries of the β grains, Fig. 4.

At the highest forging temperature (970 ºC) the coarse grained structure of the developed α + β phase with the primary envelope of the α phase at the β grain boundaries occurs, Fig. 5.
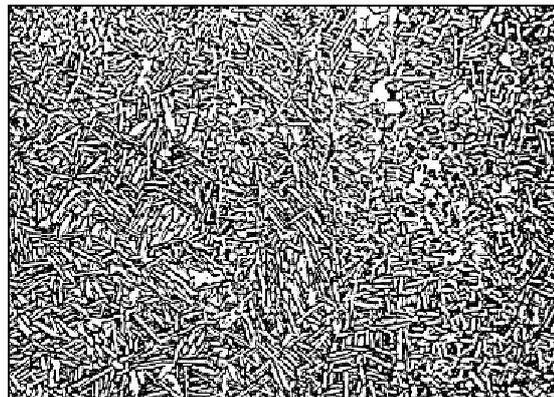

Fig.5 **Longitudinal section**, mag. 500x

The grain size according to the forging temperature is given in Table 4.

Table 4

Grain size according to forging temperature

Forging temperature, ºC	Grain size according to ASTM
950	8
960	8
970	9

Conclusions

To produce a fine grain optimum homogeneous structure the following conclusions can be drawn from the experimental results.

1. The forging temperature for both alloys must not exceed T_p (polymorphous transformation temperature)
2. The finish forging temperature must be higher than the recrystallization temperature of the given alloys.
3. It is important to ensure sufficiently high strain in the entire volume of forging (min. 30%) to induce recrystallization processes in the entire volume of forging.

References

1. Kuśmierczak S. Corrosion resistance of titanium alloy, Proceedings of International conference "10th International Scientific Conference on Engineering for Rural Development"; Jelgava; 26 May 2011 through 27 May 2011. pp. 486-489, ISSN 16913043.
2. Němec M., Provazník, J. Slévárenské slitiny neželezných kovů. Vydání první. Praha. Česká technika - nakladatelství ČVUT, 2008. 137 s. ISBN 978-80-01-04116-1.
3. Machek V., Sodomka J. Nauka o materiálu, 3. část, Speciální kovové materiály. Vyd. 1. V Praze: České vysoké učení technické, 2008, 118 s. ISBN 978-800-1042-120.
4. Ptáček L., Nauka o materiálu II. Brno: CERM, 2002. 392 s. ISBN 80720424832
5. Macek K. Kovové materiály. Vyd. 1. V Praze: Nakladatelství ČVUT, 2006, 164 s. ISBN 80-010-3513-1.
6. Sedláček V., Únava hliníkových a titanových slitin. Praha: SNTL, 1989. 351 s. ISBN 80-030-0180-3.
7. Leyens C., Peters M. Titanium and titanium alloys: Fundamentals and applications. 2nd edition. Germany: DLR - German Aerospace Center, 2005. 513 p. ISBN 3-527-30534-3.
8. Joshi V. A. Titanium alloys: An atlas of structures and fracture features. Taylor & Francis Group: CRC Press, 2006. 228p. ISBN 0-8493-5010-7.
9. Pešlová F., Anisimov J., Kuśmierczak S. Corrosion Influence on Structure of Titanium Alloys. Journal of Machine Manufacturing, 2009, roč. 96, č. 1, pp. 28-30.
10. Michna Š., Kuśmierczak S., Bajcura M. Metalografie metody a postupy. 1. vyd. Prešov: Adin, 2010. 192 s. 1. ISBN: 978-80-89244-74-4.
11. Michna Š., Kuśmierczak S. Praktická metalografie. 1. vyd. Ústí nad Labem : Fakulta výrobních technologií a managementu UJEP, 2012. 245 p. ISBN: 978-80-7414-503-2.
12. Kuśmierczak S., Michna Š. Možnosti posouzení kvality tepelného zpracování ocelí metalografickou analýzou. In Strojírenská technologie, 2012, roč. 12, č. 4, s. 231-234.