Advantages of High HIP Temperature for Titanium-based Alloys Structure and Properties

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Abstract

The paper discusses hot isostatic pressing (HIP) parameters optimum values to eliminate titanium castings porosity and improve their properties. Author suggests using high temperature instead of conventional treatment at 15 to 20^{o}C lower than solid-state transformation of alpha-titanium to beta-titanium. According to research beta-titanium is more suited for HIP. It possesses lower creep resistance and yield strength, higher ductility and diffusion rate, low anisotropy of physical and mechanical properties. Researcher used different treatment parameters, all of which included rapid cooling in order to restrain grain growth. Fine structure and high mechanical properties were obtained using pressure of 140 MPa, holding at 960^{o}C for 2 hours, subsequent holding at 1050^{o}C and rapid cooling.

Keywords*: titanium, hot isostatic pressing (HIP), casting defect, temperature*

Introduction

Hot isostatic pressing (HIP) is a process that subjects a component to elevated temperature and inert gaseous isostatic pressure in a high-pressure vessel. Under these conditions internal defects within solid bodies collapse and weld up. When choosing HIP parameters the combination of pressure, temperature and holding time must provide the best conditions to eliminate internal cavities and microporosity and at the same time to prevent phases melting and merging and grain growth [1].

HIP has the same effect on alloy microstructure, as any other kind of heat treatment; therefore HIP has a direct impact on mechanical properties of titanium alloys [2]. High HIP temperature and low cooling speed is the reason of coarse platelet structure which is the main reason of properties decrease. These factors influenced conventional choice of HIP temperature [3].

Titanium has two allotropic forms: low-temperature alpha-phase and high-temperature beta-phase. Alpha-titanium has hexagonal close-packed (HCP) lattice and exists up to the temperature of 882^{o}C, while at a higher temperature beta-titanium is formed with body centered cubic (BCC) lattice. To prevent grain growth conventional HIP temperature is chosen to be 15^{o}C to 20^{o}C than solid-state transformation. For titanium alloys this temperature varies from 870^{o}C to 1000^{o}C, while holding time differs from 2 to 10 hours depending on casting size and wall thickness. Pressure is chosen be higher than yield strength at HIP temperature [4,5]. Table 1 contains HIP parameters proposed by different researchers.

Table 1 HIP parameters proposed by different researchers

Temperature,	Pressure,	Holding	Reference

°C	MPa	time, h	
900	100	-	6
1000-1150	100	-	7
950-1000	75-100	-	7
954	103	2	8
900-1000	100-120	-	9
900-950	103	2-4	5
950-1000	120	2-4	10
845-970	103	2-4	1
899	103	2	11

Despite a wide use of HIP modes with temperatures lower than solid-state transformation and taking into account characteristics of HCP and BCC lattices, high-temperature beta-titanium possesses following advantages, which can be used during HIP:

Low plastic resistance;

High ductility;

Low mechanical and physical properties anisotropy;

High diffusion rate of BCC lattice;

Low creep resistance.

These properties should encourage quick and effective defects elimination in titanium alloys castings at a temperature higher than solid-state transformation point.

Research Procedure

Research results showed that traditional HIP parameters, used for VT20 alloy, which includes 5.5-6.8% Al, 0.5-2.0% Mo, 0.8-1.8% V, 1.5-2.5% Zr, (960±10oC, 140 MPa, cooling speed – 5-8 °C /min) sometimes lead to tensile strength decrease. Researchers were faced with a task to create new HIP technology which would improve alloy properties.

In order to find the best HIP mode for VT20 alloy castings were submitted to treatment at different temperatures in Quintus QIH 0,9x1,5x2070-1400 MURC press. The chosen temperatures were: 960°C, 1020°C (solid-state transformation point) and 1050°C. Cooling rate of 40 to 50oC/min was provided to prevent grain growth. Different HIP modes used the same pressure of 140 MPa. Holding time consisted of 2 hours at 960°C with consequent holding at 1020°C or 1050°C for 1 hour. After HIP treatment mechanical tests and microstructure analysis were conducted. Mechanical properties of VT20 alloy are presented in Table 2 and microstructures can be seen in Figure 1.

Results and Discussion

As cast samples possess fine platelet structure and their mechanical properties are within norm. After conventional HIP mode with slow cooling fine structure turned coarse, this led to a drop in mechanical properties. Treatment at 1020°C with rapid cooling at 40°C /min resulted in a fine structure, though properties didn't reach the needed level. Fine lamellar structure and high mechanical properties were obtained only by samples, which were treated at 1050°C and cooled from beta-titanium temperature at 45-50°C/min.

Research results prove that the optimal HIP mode for titanium alloy VT20 must include temperature higher than solid-state transformation point. Rapid cooling from beta-titanium phase creates fine platelet alpha-titanium structure. While low temperature treatment doesn't allow to manipulate alpha-titanium grain size without its growth.

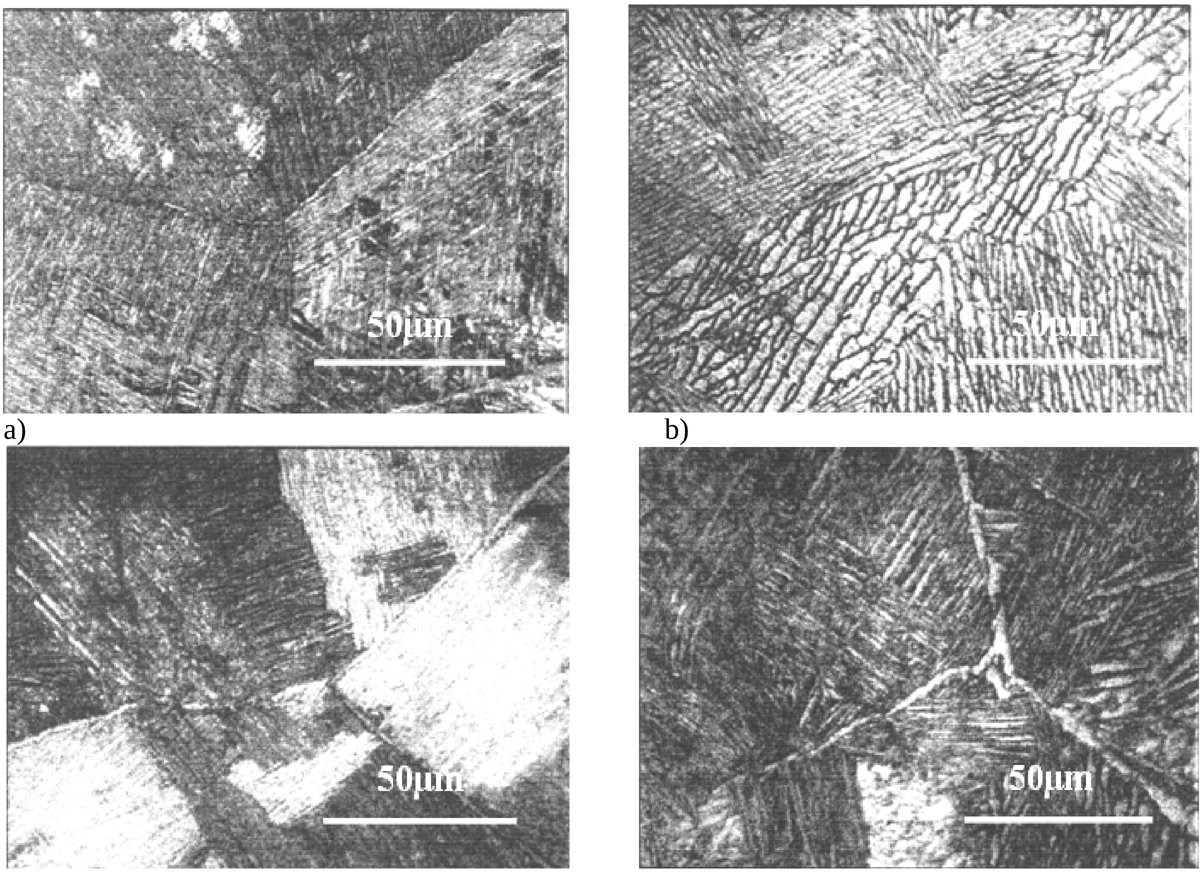
Conclusions

High-temperature beta-titanium properties are better suited for HIP treatment than alpha-titanium. According to this data, several experiments were conducted, including different treatment modes, microstructure analysis and mechanical properties tests. Based on research data the optimal HIP mode was chosen. It consists of holding at 960°C for 2 hours, subsequent heating to 1050°C and holding for 1 hour with cooling rate 45-50°C/min. This mode provides fine lamellar structure of alpha-titanium phase and high mechanical properties.

Table 2 Mechanical properties of VT20 alloy samples after different HIP modes

HIP mode	Mechanical properties				
	σ_B, MPa	δ, %	ψ, %	KCU, kJ/m²	HB
As cast	962	6.80	19.25	568.8	346
As cast + HIP, 960°C, 1 h, cooling rate 5-8°C/min (conventional technology)	889.50	10.50	21.93	653.3	360
As cast + HIP, 960°C, 2 h, 1020°C, 1 h, cooling rate	894.75	7.40	19,15	653.5	365

40^{o}C/min					
As cast + HIP, 960^{o}C, 2 h, 1050^{o}C, 1 h, cooling rate 45-50^{o}C/min	923.25	6.20	16.78	600.3	349
Standard norms	≥900	≥5	≥12	≥280	320-360



a) b) c) d)

a – as cast, heat 1; b – As cast + HIP, 960^{o}C, 1 h, cooling rate 5-8^{o}C/min (conventional technology); c – As cast + HIP, 960^{o}C, 2 h, 1020^{o}C, 1 h, cooling rate 40^{o}C/min; d – As cast + HIP, 960^{o}C, 2 h, 1050^{o}C, 1 h, cooling rate 45-50^{o}C/min;

Figure 1 Titanium alloy samples microstructure after different HIP modes, x500.

References

1. J. R. Newman, D. Eylon, J. K. Thorne. Titanium and Titanium Alloys. ASM Handbook Vol.15 Casting, 1992, pp. 1811-1836.
2. Myer Kutz J. Handbook of Materials Selection. New York, Wiley &Sons, 2002., 1497p.
3. Donachie M. J. Jr. Titamium: a Technical Guide. USA, ASM International, 2000, 216p.
4. Galdin N.M., D.F. Charnega, D.F. Ivanchuk Non-ferrous Casing Guide. Moscow, Mashinostoeniye, 1989, 528 p.
5. Eridon J. M. Hot Isostatic Pressing of Castings. ASM Handbook Vol.15 Casting, 1992, pp. 1173-1187
6. Leyens C., M. Peters. Titanium and Titanium Alloys Fundamentals and Applications WILEY-VCH GmbH & Co., 2003, 513 p. ISBN 3-527-30534-3
7. Iljin A.A., B.A. Kolachev, I.S. Polkin. Titanium Alloys: Composition, Structure, Properties. Moscow, VILS-MATI, 2009, 520 p.
8. Campbell F.C. Manufacturing Technology for Aerospace Structural Materials. F.C. Campbell– Elsevier Ltd., 2006, 617 p.

9. Bratuhin A.G., E.L. Bibikov, S.G. Glazunov. Production of Titanium Alloys Castings. Moscow, VILS, 1998, 292 p.
10. Padalko A.G. Hot Isostatic Pressing of Non-organic Materials Practical aspects. Moscow, Akademkniga, 2007, 267 p.
11. Billinghurst E. E. Jr. Tensile Properties of Cast Titanium Alloys Titanium-6Al-4V ELI and Titanium-5Al-2.5Sn ELI, NASA Technical paper 3288, 1992, 16 p.