Technology Trends in Vacuum Heat Treating

Fig. 2. Vacuum annealing of titanium sheet *(Photograph courtesy of Solar Atmospheres)*

Part Three: New Technologies and Future Developments

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In this third and final installment, we will examine technological developments in vacuum heat treating and look to the future.

Many new technologies owe their success to vacuum processing. Examples include:

- Rotational compression brazing of aerospace rocket and military jet engines
- Titanium processing including beta annealing, slow cooling and age hardening (BASCA 160) of titanium alloys
- Vacuum carburizing/carbonitriding and high-pressure gas quenching of automotive powertrain components
- High-temperature sintering followed immediately by vacuum hardening for automotive transmission components

New Technologies

Let's look at each one of these technologies a little closer.

Rotational Compression Brazing

Reusable rocket engines are a practical necessity facing NASA and other space agencies. Joint technology programs have incorporated Russian technology, most notably rotational compression brazing, in combination with channel wall construction to enhance nozzle reliability via machine-controlled processes and very low part count. Special Ag-Pd alloys (Fig. 1) are used to join the liner, jacket, stiffeners and manifold components together.

During the brazing process, a vacuum of 10^{-5} mbar (10^{-5} torr) is pulled on the inner assembly while a positive pressure of 5–6 bar is applied to the outer surfaces. This pressure differential, in combination with rotating the part during heating and brazing to counteract the forces of gravity on the braze joint, produces a superior part.

BASCA Process

Titanium and titanium alloys are annealed (Fig. 2) to produce an optimum combination of ductility, machinability, dimensional stability and structural stability. Like recrystallization annealing, beta annealing improves the fracture toughness of titanium alloys. Beta annealing is performed at temperatures slightly above the beta transus of the alloy being annealed to prevent excessive grain growth. Annealing times are dependent on the section thickness and are sufficient for complete transformation. Time at temperature after transformation is held to a minimum to control beta grain growth.

Russian and American aerospace manufacturers have collaborated to develop a unique beta-annealing process involving slow cooling and age hardening. The BASCA 160 process (Fig. 3) for alloys such as Ti-5553 (5%Al-5%V-5%Mo-3%Cr) is used to achieve tensile values in the 1,100 MPa (160,000 psi) range. The key to the process is a very precise and controlled slow cool through a defined critical range then age hardening to avoid both distortion and alpha (α) case formation.

Low-Pressure Vacuum Carburizing and Carbonitriding

Vacuum carburizing, invented and commercialized in the late 1960s (Fig. 4) was perfected with the advent of low-pressure carburizing – under 7.5 mbar (10 torr) – in

Fig. 1. Channel-wall braze joints *(Photograph courtesy of GenCorp Aerojet)*

the mid 1990s due in large part to the pioneering work on the use of acetylene as the principle hydrocarbon gas for carburizing as reported in the late 1970s in Russia (USSR Patent No. 668978).

Today, the focus is on low-pressure vacuum carburizing for advanced applications in aerospace, motorsports and automotive (Fig. 5). Technology drivers include performance enhancement and production throughput. New part designs are specifying vacuum-carburized components, and the development and use of inexpensive Cr-Mn steels is just beginning to emerge.

Carburizing cycles for new materials, especially using carburizing temperatures above 980°C (1800°F), continue to be of great R&D interest. In some cases, cycle times have been reduced by 33–50% over atmosphere carburizing – processes requiring several hundred hours. Short-duration boost cycles (in the range of seconds) and long diffusion times (in the range of hours) provide just enough carbon to the surface of the part while avoiding the formation of retained austenite, carbide networks and necklaces.

Some of these materials include:

- Aubert & Duval: X12 VDW and XD-15NW
- Carpenter Technology: Pyrowear 53, 675 and AerMet 100
- Böhler-Uddeholm: N360 Iso Extra, N695, R250, R350
- Questek Innovations: Ferrium C61, CS62, C69
- The Timken Company: CSS-42L, CSB-50NIL, CBS 223, CBS-600, BG42VIM/VAR, AF1410, HY180, HP-9-230, HP-9-430 and 300M
- Atlas Specialty Steels: BS970 and EN30B
- VSG Essen: Cronidur 30
- Teledyne Corporation: VascoMax C-250, C-300, C-350

High-Temperature Sintering and Vacuum Hardening

High-temperature sintering of automotive-transmission clutch and synchronizer hubs (Fig. 6) coupled with vacuum hardening and high-pressure gas quenching provide an example of the synergy between material selection and the heat-treating process. Product specifications mandate finish machining and heat treatment to 35 HRC. Conventional process solutions, including hard-machining operations, involve:

- FLN2-4405 (0.6%C, 1.85%Ni, 0.85% Mo) material hardened, oil quenched and tempered
- FLNC-4408 (0.75%C, 0.85%Mo, 2.0%Cu, 2.0%Ni) material sinter hardened

Finding a lower-cost technology alternative led to the investigation of SL-5506 (0.6%C, 0.5%Mn, 0.5%Cr, 0.4%Ni) material. High-temperature sintering was required at 1280°C (2340°F) followed by vacuum heat treating, 5-bar helium quenching and tempering. Benefits included a reduced number of manufacturing steps (from 9 to 7) and the avoidance of the hard-turning operation.

A comparison of the technologies (Fig. 7) revealed significant quality improvement (less statistical scatter). No qualification of the spline form was performed between sinter and heat treat. The profile was held within 10 μm (0.0004 inches) and the lead within 15 μm (0.0006 inches) over 14 mm (0.55 inches).

Future Developments

The future for vacuum heat treatment is bright. Whether considering the technology from an energy or environmental standpoint or when looking to optimize material property development, vacuum processing offers the flexibility that few other technologies can match. Offering high-vacuum and high-temperature capability, precision and repeatability are only a few of its many attributes. Vacuum has the versatility to handle a handful of extremely tiny parts (Fig. 8) or massive loads (Fig. 9) and anything in between. Areas of particularly rapid growth are in the medical, aerospace and automotive industries. **IH**

Fig. 3. Ti-5553 castings
(Photograph courtesy of Solar Atmospheres)

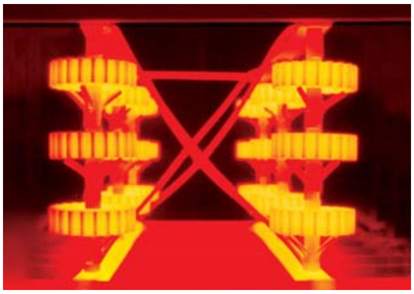

Fig. 4. First production vacuum-carburized load - circa 1969
(Photograph courtesy of C. I. Hayes)

Fig. 5. Typical LPC vacuum-carburized components *(Photograph courtesy of ALD Thermal Treatment)*

Fig. 6. Clutch and synchronizer hubs after LPC+HPGQ – SL-5506 material
(Photograph courtesy of Stackpole Ltd.)

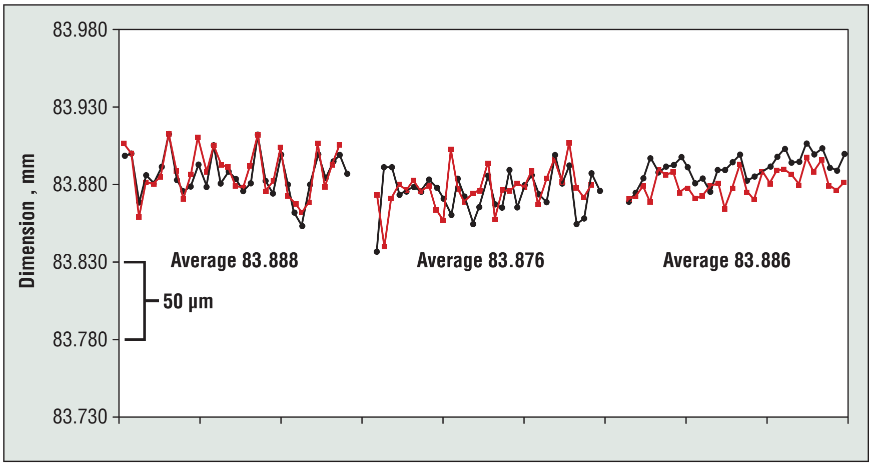

Fig. 7. Statistical process analysis – measurement over balls 0.036578 mm (0.0015 inches) – at two locations *(Photograph courtesy of Stackpole Ltd.)*

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Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: compression brazing, titanium beta annealing, vacuum carburizing, carbonitriding, high-pressure gas quench, homogenization

Fig. 8. Vacuum-carburized medical fastener *(Photograph courtesy of Midwest Thermal-Vac)*

Fig. 9. Vacuum homogenizing of titanium ingots *(Photograph courtesy of Solar Atmospheres)*