Reactive Alloy Casting Processes

Vacuum- and inert gas-melt and cast solutions for the gas turbine industry

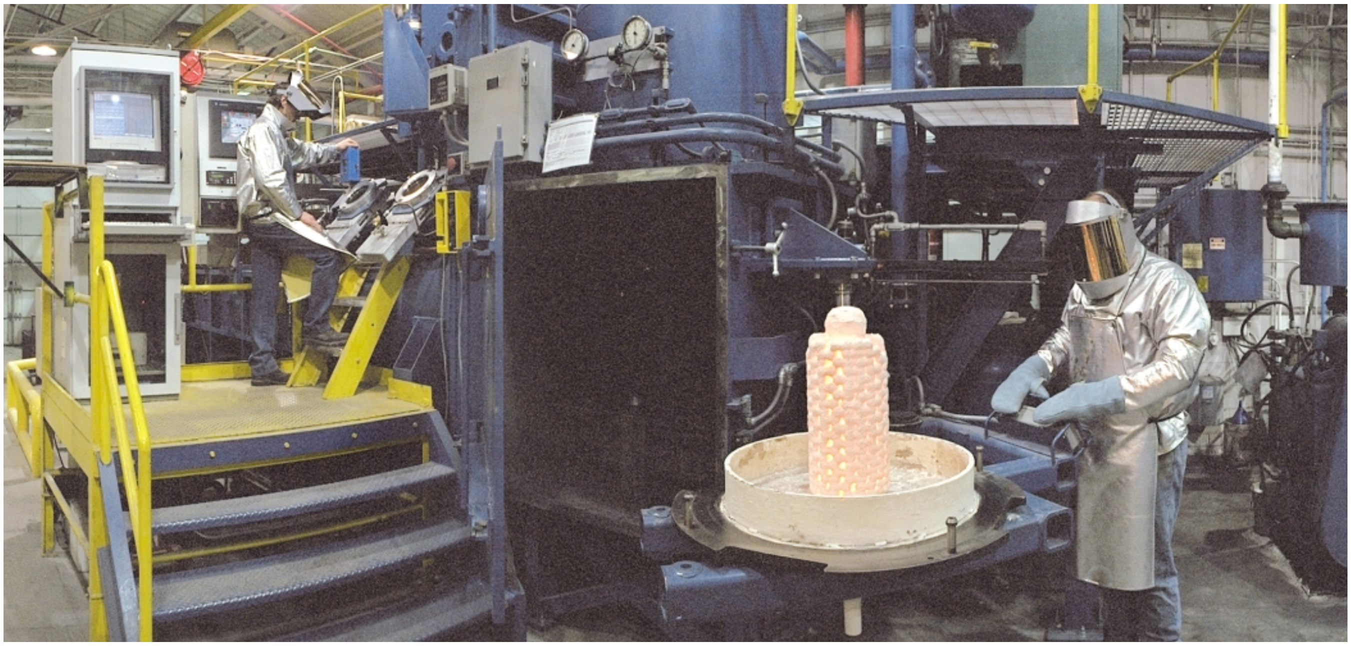

Figure 1. Extensions of the range of product manufactured by Hitchiner's Gas Turbine Division are achievable largely due to the broader capability of the new CPV Furnace.

Many reactive high temperature/high strength alloys - even those containing modest amounts of aluminum, titanium, and zirconium - can be air melted and cast for greatest commercial economy using Hitchiner's Countergravity Low pressure Air melting (CLA) process (Technical Update 2D5). Hitchiner has, for example, cast more than 10 million Nimocast 80 diesel engine precombustion chambers using the CLA process and more than one million golf irons in a drossy aluminum-bronze alloy using its CLA-CV (check-valve) process (Technical Update 3D1).

Melting and casting reactive alloys in air does, however, yield significantly more harmful oxides and nitrides than melting and casting in an inert gas such as argon or entirely under a vacuum. As a consequence, the air-melt processes do not meet the stringent standards of reactive alloy gas turbine castings. In addition, alloys containing greater amounts of the elements referenced above, or even more reactive elements such as hafnium or yttrium, require protection from the oxygen in the atmosphere to maintain chemical stability. Hitchiner has developed three processes employing inert gas or vacuum to satisfy and exceed aircraft standards, even with the most sophisticated equiaxed alloys currently in use. These complementary processes provide increasingly high levels of part cleanliness, grain size control capabilities, and the low cost characteristic of Hitchiner's Countergravity technology.

CLI Process

Hitchiner developed the Countergravity Low pressure Inert gas (CLI) melting and casting process (Figure 2) to enable the production of reactive alloy castings with melting done in an enclosed chamber under either vacuum or an inert atmosphere and casting done with the melt under a full atmosphere of argon and the mold enclosed in a separate chamber and introduced to the melt through a small opening above the melting coil. The process is the simplest and fastest of the Hitchiner reactive alloy processes. Because the mold chamber is independent of the melting unit, multiple chambers of varying sizes can be available to accommodate different sized molds. The process permits easy application of Hitchiner's check-valve (CV) innovation to production of larger, thicker castings such as diffuser cases (Figure 3) because of the freedom available for mold chamber manipulation.

Cobalt-free maraging steel, for example, is an excellent alloy for CLI casting. The mechanical properties and quality levels of CLI-cast production parts made in these alloys are excellent, with tests showing properties equal to or better than published wrought bar property minimums (Table 3). The mechanical properties of cast-to-size and machined-from-airfoil test bars made from CLI IN 713 castings are equivalent to those cast using conventional vacuum melting equipment (Tables 1 and 2).

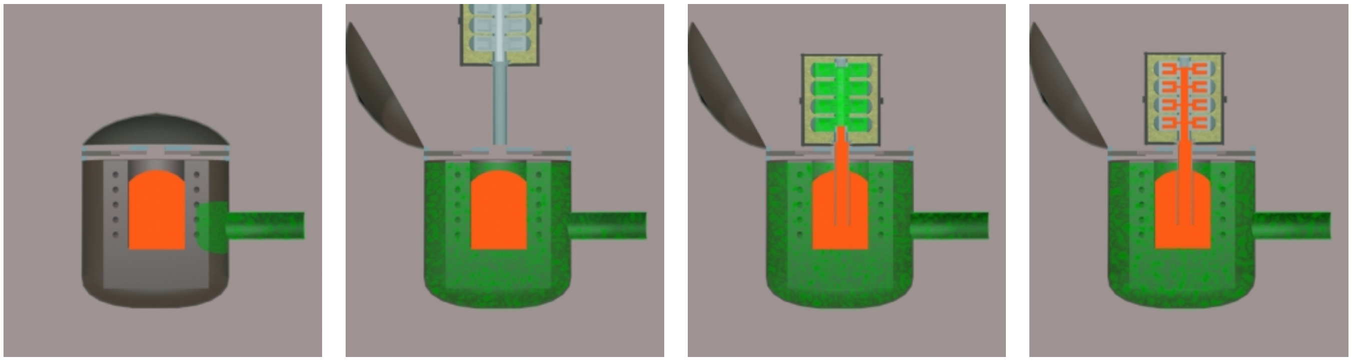

Figure 2. Countergravity low-pressure inert gas melt (CLI) process sequence. To prevent harmful oxygen contamination, Hitchiner uses patented techniques to blanket the melt with inert gas when casting titanium- and zirconium-base alloys.

Titanium-base alloys have also been successfully cast using the CLI process in Hitchiner's Metal Casting Technology facility. Ceramic crucibles are used, but the rapid speed of the process largely prevents harmful contamination from contact with the ceramic. Figure 4 shows the oxygen content from six heats of titanium alloy 6 - 4 and six titanium aluminide heats. While oxygen levels for titanium 6 -4 do not meet that defined in all specifications, they do meet the requirements defined for commercial applications of this alloy, as did all other elements defined in the alloy specifications.

The cost to manufacture titanium alloy castings using this process is significantly lower than when using traditional cold-wall skull melting. Fillout of titanium 6 - 4 castings is good as illustrated in Figure 5. The oxygen content of titanium aluminide alloy components has been shown to be acceptable for automotive engine valves (Figure 8) which have run successfully in a number of test engines. The combination of low cost with reasonable chemical control should continue to generate many titanium-base alloy applications for CLI.

CLV Process

Countergravity Low pressure Vacuum melting (CLV) was the first Hitchiner process developed with the intention of creating a reduced cost alternative to conventional gravity vacuum casting.

The process utilizes an entirely enclosed furnace (Figure 6) to permit melting and casting under a hard vacuum, with both the liquid alloy and the preheated mold contained in closed systems entirely protected by argon gas. CLV is now well established as an approved casting process by all of the major large turbine engine manufacturers.

Figure 3. Diffuser case CLI-cast in Inco 718 alloy. The CLI cast diffuser case measured 35 inches (889 mm) in diameter and 25 inches (635mm) in height.

The quality of products manufactured using this process can exceed that of conventional vacuum casting in some areas. CLV's smooth, bottom entry mold filling features far less turbulence than gravity casting and, even when the conventional casting is done under an excellent vacuum, greatly reduces the incidence of oxide formation.

This significant effect can be seen on an intermediate-sized GMR 235 component at fluorescent penetrant

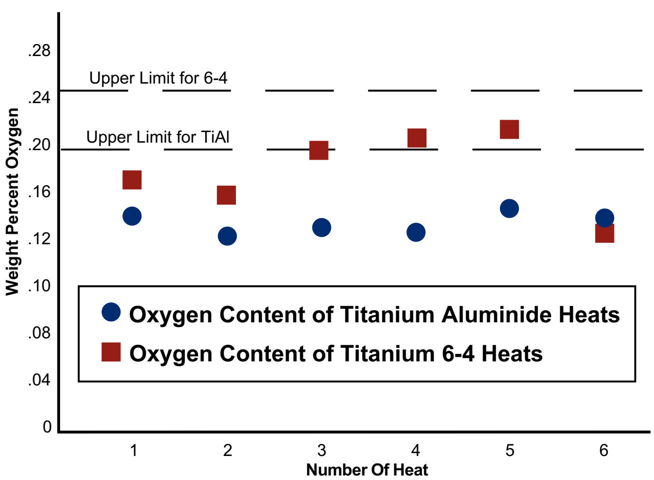

Figure 4. Oxygen content of titanium aluminide and titanium 6-4 CLI-cast heats.

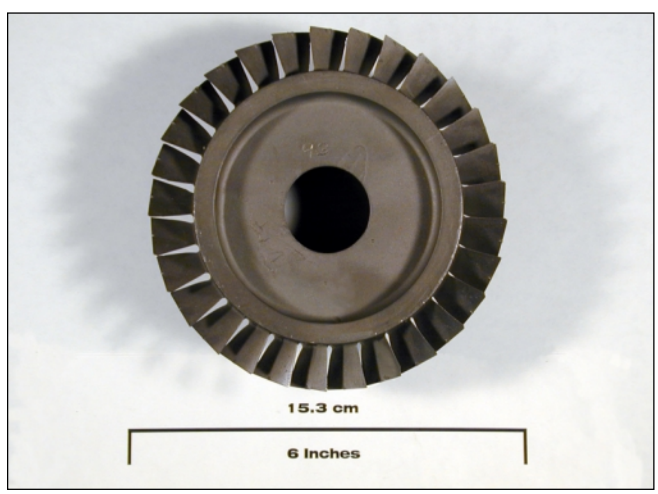

Figure 5. Small, 5-inch (127-mm) diameter titanium 6-4 alloy turbine wheel cast by CLI.

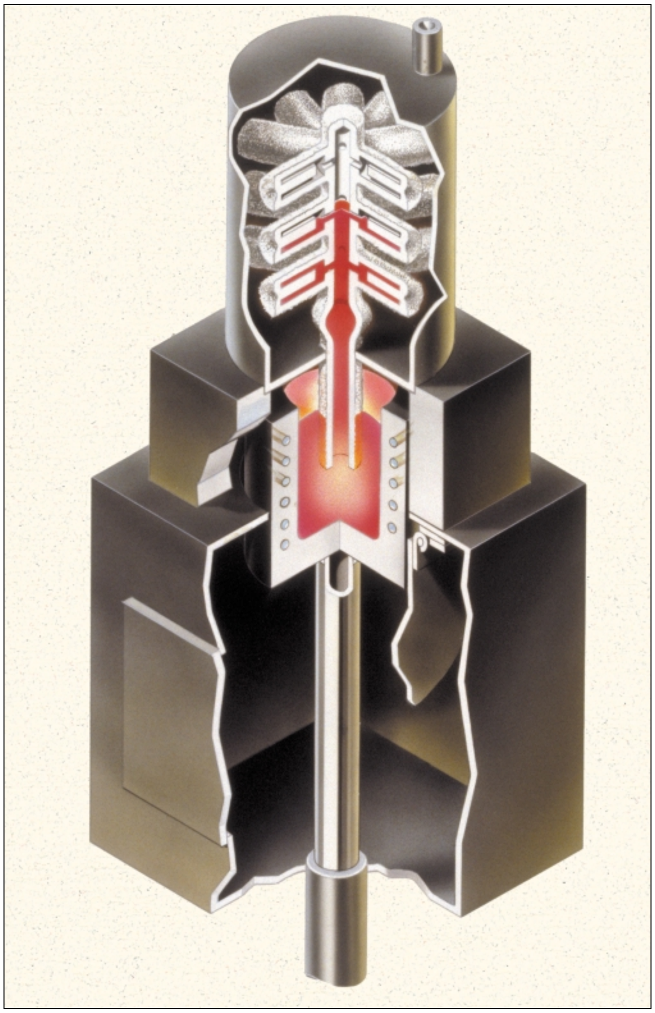

Figure 6. Countergravity low-pressure vacuum melt (CLV) process.

inspection (FPI) in Figure 7. Similarly, when Hitchiner conducted an internal trial and cast 600 thin-walled René 125 parts using CLV and conventional vacuum casting, evaluations for oxide indications showed the CLV-cast parts to have had only 15% as many indications as the parts gravity-cast under vacuum.

Many oxide indications are small enough to meet specification limitations for thick-walled parts. The indications become significant, however, in thin-walled product applications such as gas turbine combustor liner segments (Technical Update 1D4, Figure 2). The improved metal cleanliness and enhanced mold fillout at the lower temperatures made practical by the CLV process make it a more economical manufacturing method for parts with wall thicknesses ranging from 0.060 down to 0.015 inch (1,5 to 0,38 mm) than traditional vacuum casting. Figure 3 in the referenced Technical Update 1D4 shows a part typical of this product family.

CPV Process

The newest of Hitchiner's foundry enhancements is Countergravity Positive pressure Vacuum casting (CPV). The furnace itself, shown in Figure 1, represents our newest effort at the continual improvement of both our process and our product capabilities. The CPV process combines longer time spent under vacuum (instead of inert gas) for both the melt and the mold, minimizing the oxygen available for oxide formation during the melting and casting cycles. Aluminum oxide forms at remarkably low pressures, and no casting process can completely prevent oxide formation. But remarkably clean parts can be cast by maximum removal of oxygen from the mold / liquid metal system.

With this process, metal is moved into the mold using the application of argon pressure only in the area inside the crucible directly above the melt surface, and even then, only after the fill pipe has already penetrated below the surface of the melt. Meanwhile the entire mold chamber and the remainder of the furnace remain under hard vacuum. There is no gas contained within the mold which must diffuse through the mold wall to escape, so there is no resistance due to gas back-pressure to entry of liquid metal into even the thinnest sections of the mold cavities. Mold filling is therefore controlled entirely by modulation of argon pressure over the melt surface, which can be done very controllably and with precise reproducibility. For these reasons, even thinner sections can be cast, or, when desired, casting can be done at even lower metal and mold temperatures. The CPV process enables Hitchiner to produce challenging cast shapes while controlling grain sizes to finer, more uniform structures, and metal cleanliness to oxide levels not previously economically achievable in the industry.

Summary

Each one of Hitchiner's three reactive alloy casting processes has application-specific advantages appropriate to its unique strengths and capabilities. Because cost and quality requirements vary with part design, alloy, and application, let our engineers work with you to select which one will best suit your needs.

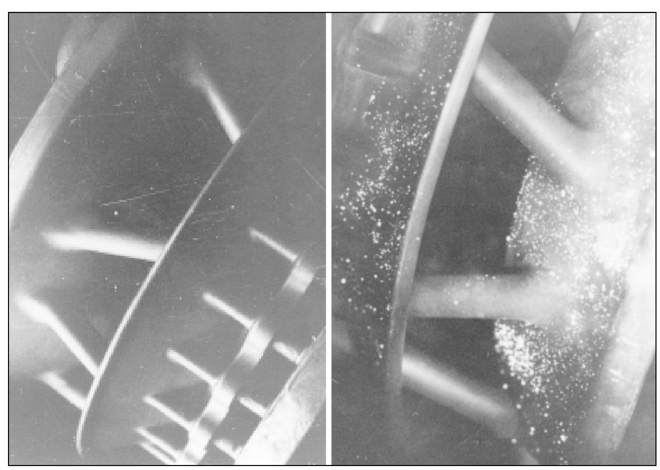

Figure 7. Black light photographs of a CLV-cast and a comparable gravity vacuum-cast 45- pound (20.5 kg) GMR235 gas turbine support. The CLV-cast part has only a small fraction of the small oxide indications seen on the gravity-cast part.

CLI Properties of Inco 713 from Cast Test Bars				
Melt	Room Temperature Properties			
CLI-cast	Tensile Strength ksi (MPa)	Yield Strength ksi (MPa)	%Elongation	Hardness Rc
No. 0110[1]	120.9 (833)	105.5 (727)	9.9	37.5
No. 0111[1]	120.2 (828)	110.3 (760)	11.0	36.0
No. 0112[1]	121.8 (839)	120.4 (830)	5.9	36.0
Vacuum-cast[2]	95-136 (655-937)	91-118 (627-813)	0-11	—
Specified min.	110	100	3.0	—

1 Three-test average.
2 Thirty-three-test range.

Table 1

CLI Properties of INCO 713 from Cast Test Bars		
Melt	Stress Rupture Life 1800 °F (980 °C)/22 ksi (152 MPa)	
CLI-cast	Hours	%Elongation
0110[1]	43.4[2]	11.2
0111[1]	43.8[2]	14.2
0112[1]	42.1[2]	11.1
Vacuum-cast[3]	12-120[4], 38	15-23, 11.6
Specified min.	30.0	5.0

1 Two-test average.
2 Stress increased after 30 hours.
3 Thirty-test range, average.
4 Stress not increased after 30 hours.

Table 2

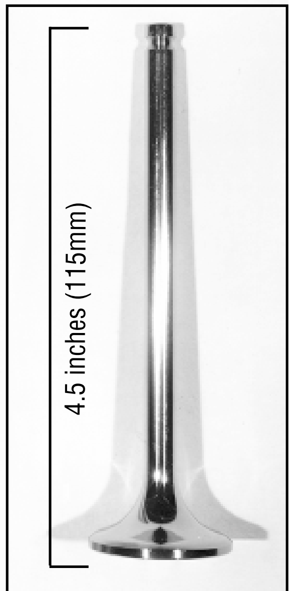

Figure 8. Cast and machined titanium aluminide automotive engine valve.

CLI Properties from Cobalt-Free Maraging Steel Test Bars					
Room Temperature Properties			Fracture Toughness, ASTME-399-90, KSI√IN[1, 2]		
Property	Range ksi (MPa)	Five-Bar Avg. ksi (MPa)	Type	Wrought AMS 6519	CLI-Cast
Yield Strength	233-235 (1605-1619)	233.6 (1610)	Standard	79.4	90.5
Tensile Strength	246-249 (1695-1716)	247.6 (1706)	Dynamic	76.0	94.1
% Elongation	9-10	9.2	Standard -35 °F (-37 °C)	67.7	80.7
%Red. in area	41.9-44.9	43.0	Dynamic -35 °F (-37 °C)	67.6	81.6

1 Required minimum for bar stock.
2 Average of two tests.

Table 3