Laser Powder Fusion Welding

David Kaser, Huffman Corporation

Introduction

Laser research over the past 15 years has led to the development of a unique method for depositing complex metal alloys onto the repair surface using laser beams as the source of energy. This novel technology, which has become known in industry as Laser Powder Fusion (LPF), offers a broad range of potential applications in the fields of metal welding and cladding. This technology has been accepted by leading engine manufacturers such as General Electric, Pratt & Whitney, Allied Signal, Rolls-Royce, Allison, Pratt & Whitney Canada, Solar and MTU.

Early in the development, gas turbine families of parts were identified as attractive components to take advantage of the full potential of Laser Powder Fusion Technology. Their design and metallurgy demanded low heat input, rapid deposition rates and narrow dimensional tolerances. As a result, state-of-the-art Laser Powder Fusion Systems are currently witnessing increased utilization in the rapidly expanding civil, industrial and military engine component fabrication and repair markets. The compressor and turbine sections of all engines contain critical and sensitive components such as turbine blades, vanes, rotating air seals, cases, shrouds, discs, and stator assemblies, all of which are candidates for repair procedures using this technology due to their sophisticated metallurgy, complex design and high intrinsic cost.

Technical Advantages

Laser Powder Fusion Technology provides an innovative method for harnessing the intense energy generated within a carbon dioxide gas laser or solid state YAG laser by injecting a stream of fine metallic powder into the beam and depositing the molten weld pool onto a free standing substrate.

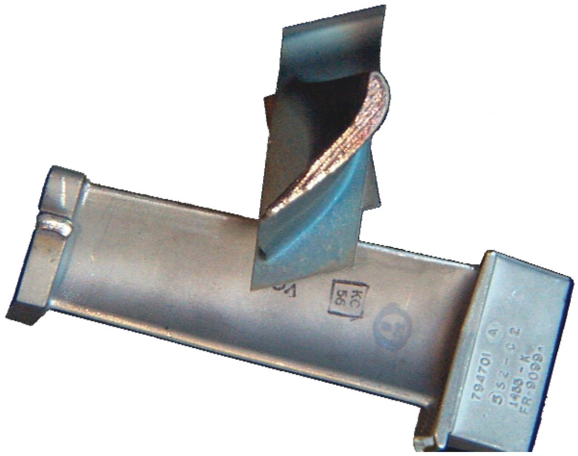
The narrow attenuated beam of photons in the laser melts the injected particles in fractions of a second - enabling the molten metal to be deposited onto the substrate in layers, ranging in thicknesses from 0.005 inches to 0.030 inches (0.13 mm to 0.76 mm) and in band widths as narrow as 0.020 inches (0.5 mm).

The technical appeal of this Laser Powder Fusion technology is its ability to deposit successive layers of metal onto the surfaces of complex components with the minimum of heat transfer. As a result, this uni-directional welding process enables highly localized areas of a component to be built up with metallurgically bonded layers of a metal

or alloy to heights exceeding 0.5 inches (12 mm) without overheating of the target substrate.

The low heat input property of Laser Powder Fusion is the most critical characteristic of this technology that makes it highly attractive for jet engine component repair applications where metal deposits are required to be applied to state of the art superalloys. These superalloys are highly susceptible to strength loss and physical distortion when exposed to excessive temperature. Conventional repair techniques, such as tungsten inert gas, metal inert gas, plasma and electron beam welding, usually induce large amounts of heat during weld metal deposition resulting in major temperature increases in the body of the component. Weakening of the base alloy occurs when temperatures rise above certain limits. This weakening along with component distortion can cause irreparable damage to the part. In contrast to this, the Laser Powder Fusion process transfers heat only to those localized areas traversed by the 0.020 inch (0.5 mm) diameter laser beam. As a result, heat inputs are order of magnitudes lower than the heat input incurred during conventional welding resulting in reduced residual stresses and distortion and a substantially smaller heat affected zone.

Hot section components are typically cast from precipitation hardened nickel base superalloys that were specifically developed to maintain their mechanical properties for long periods of time at elevated temperatures under high dynamic stresses. Despite the fact state-of- the-art superalloys exhibit high creep and fatigue strengths at elevated temperatures, they are highly susceptible to cracking and strength loss during conventional welding and certain cladding processes. This is attributable to the gamma prime in the base alloys of the component which undergoes partial dissolution and coarsening at the temperatures prevailing during TIG welding. This occurs in the heat affected zone that



does not enter the molten state during the welding process. On the other hand, Laser Powder Fusion greatly minimizes this dissolution and coarsening and hence the potential for cracking, distortion and softening during welding or cladding processes is significantly reduced. This is attributable to the significantly lower and localized heat input, which also allows for part handling immediately after welding. Moreover, Powder Fusion results in greater integrity in terms of porosity.

The appeal of the Laser Powder Fusion process has led to major technical breakthroughs including the development of precision laser welding equipment designed specifically for the manufacture and repair sectors of the gas turbine industry. Today's state-of-the-art integrated Laser Powder Fusion Welding Systems, such as those developed by Huffman Corporation (Clover, SC), enable the rate and location of the metal deposition to be precisely controlled by computer programmed translation of the laser beam and metered injection of powders into the beam. The rate of metal deposition with these integrated systems can be varied over a broad spectrum simply by changing the power level of the laser and the beam translation speed.

In order to make the equipment even more capable in terms of "net shape deposition," high-resolution vision devices have been developed and integrated into the laser control systems. These systems facilitate tightly controlled metal deposition over the highly localized surface areas that are individually defined for each component by pre-scanning the area to be welded and communicating, by way of computer, the precise dimensions and locations of the relevant surfaces to the laser translation mechanism. This enables the highly focused deposition properties of the laser beam to be maximized by compensating for minute changes in the geometry of each part.

Clearly, this feature enhances the ability of the technique to produce near net shape metal deposits on repaired surfaces. The vision system guides the repair technician in the control of the laser power input according to the geometry of part, material thickness, process feedrates, weld path location, number of layers applied, and direction and sequence of weld.

Invariably, gas turbine repair applications for Laser Powder Fusion involve components that require metallic build-up of exposed contact surfaces in order to restore worn critical dimensions that have been degraded during engine operation and have fallen outside of acceptable dimensions. These modes of degradation, caused by wear, erosion or corrosion are most frequently experienced on the knife edge and fin seals that are integral features of certain turbine blades, turbine vanes and rotating spacers. Restoration of these components to blueprint dimensions during refurbishment is critical to ensure continued efficient performance and reliability of the engines. However, this restoration has to be accomplished without impairing the base material properties or the design tolerances of the component - conditions that can best be assured by utilizing the Laser Powder Fusion technology.

For example, the repair of a 10 inch (250 mm) diameter rotary seal with 7 air seals by conventional Dabber TIG welding was compared with the same repair performed with Laser Powder Fusion welding. The conventional method required approximately 8 hours for the repair with

approximately 0.035" (0.9 mm) of inside diameter shrinkage. Utilizing laser powder, the repair was completed in approximately 55 minutes with approximately 0.010" (0.25 mm) inside diameter shrinkage.

In a similar manner, the tip rub surfaces of non-shrouded turbine blades must be restored during refurbishment in order to minimize the gas leakage between the blades and outer shroud assemblies. Since these non-shrouded blades are normally employed in the high turbine sections where temperatures are the highest, they often require tip build up with high strength precipitation hardened superalloys rather than weaker solid solution hardened alloys. This requirement has encouraged overhaul agencies to investigate Laser Powder Fusion as a repair technology since it is capable of eliminating the problems normally associated with TIG weld deposition of gamma prime hardened filler alloys.

The Laser Powder Fusion process is also gaining acceptance as the

method of choice for applying hard face alloys to those areas of components that experience severe fretting during engine operation. In many of these applications, such as the hard faced "Z" notches of turbine blades, Laser Powder deposition of cobalt tungsten carbide is starting to displace the traditional carbide plasma coatings that are prone to spallation and the TIG deposited cobalt/tungsten carbides which are prone to alloy dilution and base metal cracking.

Applicability Advantages

Laser Powder Welding Systems utilizing CO2 Lasers also have the advantage of being used in the welding mode without powder injection. This is accomplished simply by changing the powder fusion nozzle to a standard welding nozzle and disconnecting the powder. Such systems are also capable of cutting complex shapes utilizing the CO2 Laser. This enables a single piece of equipment to serve three distinctly different requirements in the manufacture and repair of gas turbine components.

Closing

Applications for Laser Powder Fusion in mature gas turbines are numerous. However, an even greater potential exists for the application of the Laser Powder Fusion process in state-of-the-art turbine engines. Today, advanced gas turbines are being fitted with single crystal and directionally solidified components in order to achieve maximum thermal efficiencies by operating the engines at higher turbine inlet temperatures. In the manufacture and repair of such engines, Laser Powder Fusion is rapidly being recognized as a critical and essential technology, and in some cases the only repair technology, since the oriented airfoil castings are highly susceptible to re-crystallization when subjected to the intense heat induced during conventional weld repair.

Technology Comparison

Process Specifics (GE CF6-6 Stage 2 HPT Blade)

Technology	Pass Height	Pass Width	Productivity
Manual TIG	0.100" – 0.200" (2.54mm-3.05mm)	0.300" (7.62mm)	4-5 Per Hour
PTAW	0.040" (1.016mm)	0.040" (1.016mm)	6-10Per Hour
Laser Powder Fusion Welding	0.020" (0.51mm)	0.060"-0.075" (1.52mm-1.91mm)	25-30 Per Hour

Note that the laser power fusion welding process is significantly faster than the other processes with precise near net shape material deposition.

Financial Advantages

The low heat and weld metal input and highly localized deposition features of LPF make the process highly cost effective in terms of material consumption and enable surfaces to be restored to near net shape of the final product. Conventional welding techniques, on the other hand, consume far more filler metal and result in heavy and uneven weld deposits necessitating expensive post-weld machining operations in order to restore the dimensions of the component to within blueprint tolerances. The following chart compares the manual TIG process, the Plasma Transfer Arc Welding (PTAW) process and the Laser Powder Fusion welding process of a GE-CF6-6 Stage 2 High Pressure Turbine Blade.

Volume Fraction of Coherent Gamma Prime in Single Crystals

ALLOY	%
PWA1480	69
CMSX-2	68
CMSX-4	71
CMSX-6	60

First and second generation of single crystal alloys have far higher aluminum and tantalum contents than equiaxed alloys rendering them even more susceptible to cracking and base alloy dilution during conventional weld repair. This is related to the highest volume fraction of gamma prime which often exceeds 65 percent in advanced single crystal alloys as compared to above 55 percent or less for co-axed alloys. The Laser Powder Fusion process provides a technique whereby such sensitive alloys can be welded with a broad variety of high strength filler metals without the mechanical property degradation resulting from re-crystallization, cracking or alloy dilution. The Laser process also produces a weld deposit having the same radial orientation as the single crystal or directionally solidified casting which further enhances the properties of the weld. The refurbishment of damaged surfaces on these single crystal components by Laser Powder Fusion is also an economic necessity because of the high intrinsic value of the components and the high replacement cost when the components are scrapped. Laser Powder Fusion repair of single crystal and directionally solidified airfoils is rapidly becoming a core competency in the gas turbine repair industry.

Single Crystal and Directionally Solidified Repairs using Laser Powder Fusion

ENGINE	COMPONENT
JT9D-7R4D/G	TB1
JT9D-7R4G	TB2
PW-4000	TB1/TB2
PW-2037	TB1
V2500	TB1/TB2
F110	TB1
F100	TB1
CF6-80C2	Stage 1
CF6-80A	Stage 1
CF6-50	Stage 1
CF6-50 PIP	Stage 1
CF6-6	Stage 1
CF6-6	Stage 2
CFM56-2	
CFM56-3	
CFM56-5	
CF6-80C2	Stage 2
CF6-80A	Stage 2

The list of powders used in the Laser Powder Fusion technology is continuing to grow.

Partial List of Laser Powder Fusion Powders Used to Date

Inconel 625	PWA 694
Inconel 713	PWA 795
Inconel 718	PWA 1447
Inconel 738	Mar M247
Inconel X750	Stellite 694
Inconel 901	Waspalloy
MAR M002	Haynes 188
Hastelloy X	Rene 80
Travelloy	Rene 142
CM 64	Nimonic 90
C263	GTD 111
Titanium 6-4	Stainless 410

Aero engine and industrial engine component remanufacturing is becoming more competitive worldwide. Advanced technology methods are required to satisfy the yield, reliability and speed required to remain cost effective as Laser Powder Fusion welding and related machining processes are meeting this challenge and providing present and future solutions for the component repair industry.‡

HUFFMAN CORPORATION
1050 Huffman Way • Clover, SC 29710 • USA
1 . 8 8 8 . H U F F M A N
w w w . h u f f m a n c o r p . c o m