# Increasing life through repair

## NEW PROCESSES HELP TO RESTORE REPAIRED PART CONDITION TO 'AS NEW'

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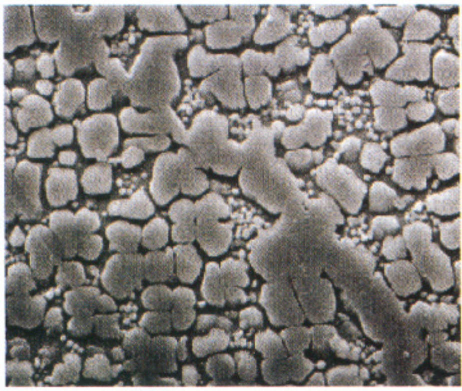
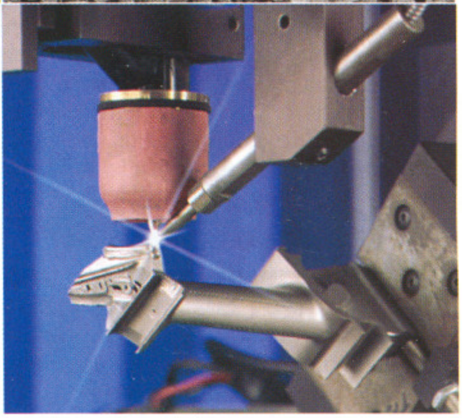




*Clockwise from top*

*Figure 1: GTD111 alloy after 24,000 hours of service showing an aged gamma-prime microstructure*

*Figure 2: GTD111 alloy after rejuvenation heat treatment with a restored microstructure and properties*

*Figure 3: Superalloy welding with specialized weld alloys through an automated microplasma welding system*

Fuel and maintenance are the two main contributors to the operating costs of a gas turbine power plant. The most significant maintenance cost is the replacement of hot-gas-path components when they reach the end of their reliable life. Operators therefore search for ways to extend the lives of these expensive components to reduce plant lifecycle costs.

New component repair technologies are now being employed to extend component lives. In many cases, these advanced repair processes are achieving two times the life extension achieved with conventional repair methods. Savings are significant since the cost of even the most advanced repair is a small fraction of the avoided cost of new replacement parts.

## Benefits of rejuvenation

Specialized processes or "enabling technologies" that have been developed for application in component repair include:

- "Rejuvenation" heat treatment to restore the alloy structure and strength for high-hour turbine blades and buckets
- Stripping processes that enable the internal coatings to be effectively stripped and replaced with new coatings
- Specialized repair materials used in welding and brazing to achieve higher strength and oxidation-corrosion resistance

Over the last 10 years, these technologies have proven to reliably extend by up to two times the life of mature E-class components. As an example, Frame 7EA bucket sets have been operated to 100,000 - 120,000 hours reliably through the application of full-strip and re-coat of the internal and external coatings, followed by rejuvenation heat treatment to restore alloy strength. The eight-year life extension has resulted in a savings of over $5 million — savings is calculated as the avoided new part purchase price less the cost of advanced repairs — for a fleet operator with four turbines.

Advanced repair technologies have also been successfully applied to the latest generation of aero-derivative components in the same ten-year period. Since F-class components are based on aero-engine alloys, cooling designs, and coating systems, it was a logical extension to adapt and apply these processes to the latest generation of industrial frame engines.

Heat treatment is used during the repair process to improve weldability, stress-relieve welds, and to diffuse coatings. However, these processes are not designed to restore the microstructure and material properties, which have deteriorated from high-temperature exposure.

Rejuvenation heat treatment cycles are designed to restore the alloy microstructure and creep strength, and to return the parts to their original, as-new condition. The rejuvenation process involves several heat treatment cycles and can include both high-pressure and vacuum heat treatment.

A high-pressure Hot Isostatic Pressing (HIP) process may be incorporated as a first step to fully dissolve and recondition the microstructure and heal any creep damage. HIP has also been used extensively in new part manufacturing by OEMs to eliminate casting porosity in high-performance blades and vanes.

Subsequent rejuvenation heat treatment is performed in a vacuum furnace to dissolve and then re-precipitate the essential "gamma prime phase," which gives all the nickel-based super alloys their strength. The gamma prime phase is then formed into the ideal size and shape through heat treatment at lower temperature (Figures 1, 2).

Rejuvenation heat treatment can prepare the blades to be run for a similar service interval as the first time. Blades that need rejuvenation at 48,000 hours will run reliably for an additional 48,000 hours of similar service after rejuvenation.

Rejuvenation heat treatment has been applied and proven with reliable results since 1980 for industrial frame engines, and since 1994 for aeroderivative engines. The process has been applied to F-class blade alloys, such as GTD-111 DS (Directionally Solidified) used in the GE Frame 7FA, MM247DS alloy used in the W501F/G, and PWA 1483 Single Crystal used in the Siemens V84/94.3A.

To re-certify a set of rejuvenated blades, sample material is subject to the same heat treatment process as in the rejuvenation process, and subsequently processed through qualification tests. This generally involves an examination of the microstructure and mechanical testing (stress rupture tests) to ensure the rejuvenated material meets the original new material specifications.

Most of the F-class stage 1, and sometimes stage 2 blades, suffer oxidation metal loss at the tips due to the high operating temperatures of these engines. The tip height must be restored by weld build-up and machined to the original dimension to re-establish engine performance. The selection of the weld metal used to restore the tip is critical in preventing future oxidation when the blades are returned to service.

Specialized, oxidation-resistant weld alloys with high aluminum content can provide greater oxidation resistance than the original blade alloy and are now available. Weld alloys, such as Rene142 and MM247, when applied to the blade tip, produce an upgraded part for future service. These weld alloys have proven themselves in advanced aero and aeroderivative engines for several years, and are now being applied in the advanced repairs for stage one GE Frame 7FA and W501F blades, and Siemens V84.3A single crystal blades.

An example of the advantages of these specialized weld metals is the RB211 aeroderivative blade, which has suffered extreme metal loss in service due to high-temperature oxidation. This problem was solved by incorporating a special oxidation-resistant weld alloy in the advanced repair, and these parts now achieve extended service intervals — up to two times previous service limits with no metal loss. The same weld alloy is now being used for F-class industrial parts.

Oxidation-resistant weld metals are high-strength, and as such are highly alloyed and tend to be difficult to weld with. This has led to the introduction of automated welding processes (Figure 3) to achieve the precision heat control needed to weld these alloys. Laser and microplasma welding systems used in the aero industry are now being used to successfully weld directionally solidified and single crystal blade tips of F-class machines for improved oxidation resistance.

## Stripping internals

Removal and replacement of external coatings is a normal step even in conventional component repair. F-class blades and vanes have internal coatings to protect air passages from oxidation at high operating temperatures. These internal coatings must be effectively removed in order to carry out advanced repairs that extend component life. Internal coatings are removed for two reasons. First, they may be exhausted and need to be replaced for continued protection of the parts. Secondly, in order to process the parts through the high temperatures required for rejuvenation, all coatings must first be removed.

Stripping processes all use mixtures of acids that are designed to dissolve the remaining coating. An effective internal stripping process must first be capable of penetrating the thin oxide layer on the surface in order to contact and dissolve the coatings. The oxide layer on the external surface is easy to access and can be removed by a light grit blast — but this is not the case with internal coatings. The inability to strip and replace the original coating often becomes the life-limiting factor for the component — either due to oxidation attack of internal surfaces or the inability to apply rejuvenation heat treatment. For this reason, today's advanced blade repair includes the replacement of internal coatings.

Coating selection often offers the best opportunity for life extension. The first opportunity to evaluate the performance of the original coating arises when the parts are removed from service and sent for refurbishment. Metallurgical analysis can be used to determine if a different coating would be better suited to the specific environment, location, operating practices and so forth. While the OEM may be limited to initially offering a general purpose coating for all applications, a refurbishment facility can offer a wide range of coatings.

For F-class components, MCrAlY overlay coatings are used for external airfoil surfaces. These coatings are deposited by a thermal spray process. Since this method relies on minimal reaction with the base alloy, MCrAlY coatings offer greater freedom to vary the composition mix. The coatings can be tailored to suit the application to a greater extent than is possible with diffusion aluminides.

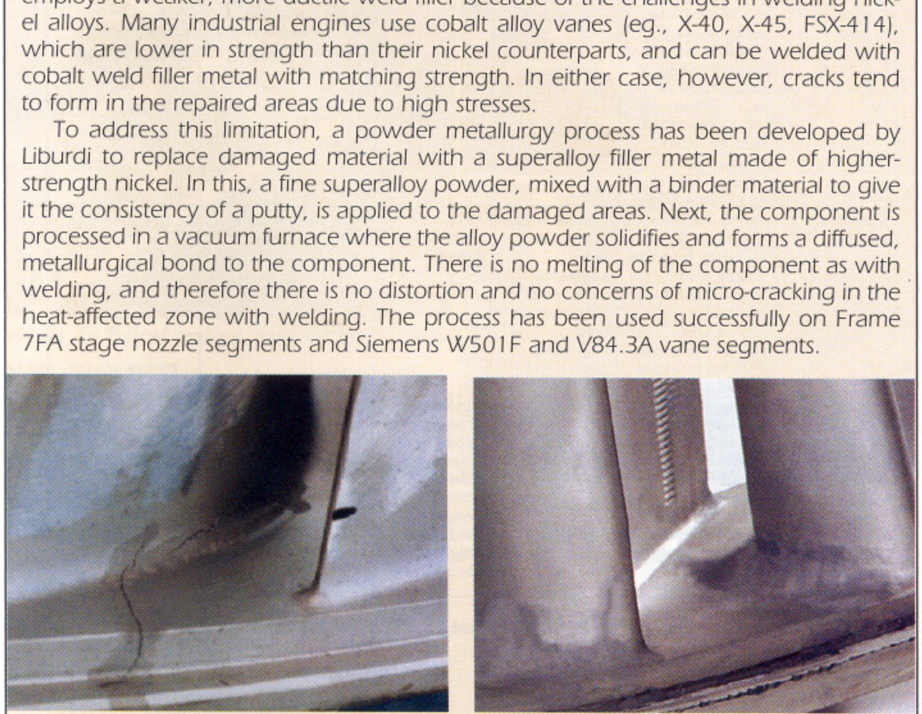
For a specific plant environment and operating regime, a replacement coating may be selected that offers greater corrosion protection, oxidation protection, or ductility and resistance to cracking. Similarly there are different classes of Thermal Barrier Coatings (TBC) that are applied over MCrAlY, which may be selected for improved durability for the type of service. Often the choice for F-class components is an MCrAlY coating with similar oxidation resistance to the original coating, but which is less prone to cracking in service.

Cracks in coatings can be a significant maintenance problem since they can lead to forming cracks in the base metal. This increases repair work, and in some cases may make the parts un-repairable.

## USING POWDER METALLURGY

Conventional welding of nickel alloy vanes (eg., GTD222, Rene80, IN738) usually employs a weaker, more ductile weld filler because of the challenges in welding nickel alloys. Many industrial engines use cobalt alloy vanes (eg., X-40, X-45, FSX-414), which are lower in strength than their nickel counterparts, and can be welded with cobalt weld filler metal with matching strength. In either case, however, cracks tend to form in the repaired areas due to high stresses.

To address this limitation, a powder metallurgy process has been developed by Liburdi to replace damaged material with a superalloy filler metal made of higher-strength nickel. In this, a fine superalloy powder, mixed with a binder material to give it the consistency of a putty, is applied to the damaged areas. Next, the component is processed in a vacuum furnace where the alloy powder solidifies and forms a diffused, metallurgical bond to the component. There is no melting of the component as with welding, and therefore there is no distortion and no concerns of micro-cracking in the heat-affected zone with welding. The process has been used successfully on Frame 7FA stage nozzle segments and Siemens W501F and V84.3A vane segments.



***Figures 4, 5: Frame 7EA Nozzle after 24,000 hours service repaired with a standard weld (left) and an advanced powder metallurgy process (right)***

**Author**

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