Repair Techniques for Hot Gas Path Components in Industrial Gas Turbines

The methods used to repair turbine components from Industrial gas turbines are reviewed and explained. Particular reference is made to cleaning, heat treatments, welding, brazing, machining, coatings and inspection.

INTRODUCTION

Repair of turbine components is now a procedure accepted by most operators. Few however, have the resources to carry out the repairs themselves. This has led to the development of companies offering repair services to turbine operators. The repair methods and limits for flying gas turbines are detailed by the engine manufacturer and are commercially available in manuals. This is not generally the case for heavy industrial gas turbines where each repair company has developed its own repairs. The main techniques used in the repair of hot gas path components from industrial gas turbines are however widely used and are set out in the paper.

CLEANING

Cleaning can be said to be the most important part of any repair scheme. Its success controls the success of all the other processes. It is also necessary to remove the turbine contamination to determine the condition of the part. Without successful cleaning, welding and brazing operations are difficult or even impossible and during heat treatment the remaining dirt diffuses into the base material weakening the structure.

There are several methods of cleaning in regular use.

Abrasive Blast Cleaning

Abrasive Blast Cleaning (figure 1) is the most effective method of removing large quantities of dirt and scale from the surface of engine run turbine parts. Abrasive medium is injected into the air stream either by forcing it into the airline from a pressurised container (the pressure feed method) or by the suction of a vacuum created in the nozzle (the suction feed method). Hand controlled air nozzle systems are preferable for their versatility and ease of use on a wide variety of parts having varying amounts of contamination. The pressure feed method is a much more aggressive process, which can easily erode the base metal. It is therefore only used for the initial cleaning process, while the suction system is used as an in process cleaning aid.

The most effective abrasive medium, both in terms of cost and performance, has been found to be Aluminum oxide particles. These angular particles are used in the 80 mesh, rougher size, for the first cleaning operation in the pressure cabinet and then in the finer 220 mesh in the suction cabinet to produce a smoother surface for in process work. It is necessary to use angular particles to break up and remove surface contaminants, rather than rounded shot which will compact any foreign matter into the surface. One example of the use of abrasive blasting is before fluorescent penetrant inspection. Practical experience during repair has shown that machining processes such as belt grinding smear the surface irregularities and cover micro-cracking. By deburring the surface with abrasive particles a more accurate crack inspection can be carried out.

The one exception to the angular...
Chemical Cleaning

Many of the latest designs of turbine components now have protective coatings applied during manufacture. Coating remain have to be removed before repair to facilitate inspection and reduce contamination of welding, brazing and coating operations. The parts are immersed in mixed acid solutions which are designed to attack the coating only.

Reducing atmosphere

While abrasive blasting can clean the exposed surface of a part, it cannot entirely clean cracks or internal surfaces. This is done under a reducing gas, such as hydrogen or halide containing gases at high temperatures.

Hydrogen is the most commonly used. Parts are placed in a closed retort and then a constant flow of hydrogen gas is passed through the retort. The hydrogen reduces the metal oxide to the metal plus water. Reaction length is dependent on the amount of contamination present. The water content of the gas exiting the retort is measured to determine how far the reaction has progressed. The process is temperature related. Normally the high temperature solution heat treatment cycle for an alloy is used to prevent detrimental effects on the base material structure.

While theoretically hydrogen can reduce all metal oxides to metal plus water \( \text{(1)} \), practically this is not possible. In the case of the more stable oxides, such as that of aluminum, the purity of hydrogen required is not obtainable in a production process. To effectively remove Aluminum oxide and Titanium oxide Halide containing gases can be used. A method of producing one of these highly aggressive gasses has been developed utilizing the decomposition of Teflon at temperature \( \text{(2)} \). During the reaction Carbon Tetrachloride gas is produced which reacts with both contaminants and the surface of the superalloy. The result is a thin surface layer with low Aluminum and Titanium concentrations, but rich in Chromium. This surface is highly suitable for brazing, welding and recoating operations.

Heat Treatments

Heat resistant nickel based superalloys are precipitation hardened by gamma prime, while Cobalt based superalloys rely on the formation of carbides to strengthen them.

The first step of the heat treatment is a high temperature solutionizing treatment at about 1150°C, dependent on alloy. The solutionizing aids weldability in low gamma prime superalloys (3). In the case of parts run for long periods at high temperature the solutionizing makes the material more ductile by dissolving the brittle carbides and sigma phases that have precipitated along the grain boundary back into the material matrix. This is followed by one, two or even three steps aging treatment in the range of 750°C to 1080°C which restore the high temperature creep resistance, an important property in highly stressed turbine blades.

During manufacture turbine components are heat treated at predetermined temperatures and for set times to obtain the optimum material properties. Operation at high temperature degrades these properties. Typical problems are loss of ductility and decrease in creep resistance \( \text{(4)} \). Provided that the material is re-heat treated before the degradation is too great, the material structure and properties can usually be recovered. It is necessary to control the heat treatment very carefully to obtain the maximum effect and to reduce distortion and cracking problems. Superalloy material manufacturers supply details of the optimum heat treatment to obtain the best material properties for their product. While this is an important guide, some variations have to be made in the repair process, as the heat treatments were devised for materials in the as cast or forged condition, not those run at high temperatures and stresses in a gas turbine.

The temperature rise during the heat treatment must be regulated to control distortion and cracking caused by metallurgical changes and induced stresses \( \text{(5)} \). The complicated form of turbine nozzles and blades with their adjacent thick and thin sections can cause distortion problems. The larger mass of a thicker section takes longer to heat up than the smaller mass of a thin section. The temperature of the thin section therefore rises more rapidly and expands further than the heavier stronger section. This can result in permanent plastic deformation of the material and distortion of the component, with eventual cracking of weak points. The heat up rate is therefore prescribed so as to obtain even heating of all parts of a component. On the other hand, some materials \( \text{(6)} \) require an immediate heat treatment after welding with a rapid rise in temperature to prevent post-weld heat treatment cracking. The requirements of one factor...
must therefore be carefully balanced against those of another to obtain the optimum result.

The heat treatments are carried out in different types of furnaces under protection of either inert gas, vacuum or reducing atmosphere. The uses of reducing atmosphere have already been discussed in the cleaning section.

**Fig. 2** Vacuum furnace used for heat treating and brazing Superalloys.

**Vacuum Furnace**

Besides being used for brazing, a vacuum furnace is an important heat treat- ment tool. The electrical heating can be precisely regulated to give accurate heat up rates and enable the temperature to be controlled within a few degrees during times on hold. Cooling is effected by injecting inert gas into the vacuum chamber and then circulating it through a heat exchanger. The extremely fast cooling rates that are possible, are controlled by varying the gas pressure in the chamber. The pure atmosphere can clean parts during operation by the decomposition and vaporization of contamin- ants.

**Inert Gas Atmosphere Furnaces**

While vacuum furnaces are capable of cleaning the material surface, inert gases only protect the surface from further oxidation. Due to price and availability considerations, argon is the most commonly used inert gas. The parts are placed in a retort which is filled with inert gas. Heat treatment in this type of furnace is slower and less controllable than a vacuum furnace but running costs are lower.

As a general rule with respect to cost, time and material requirements, vacuum furnaces are used for heat treatments over 1000°C and inert gas atmosphere furnaces for those below 1000°C.

**WELDING**

Welding is a commonly used method of repairing cracks and adding missing material to superalloy turbine parts. Tungsten-Arc Inert Gas Welding (TIG) is the most popular and universally used welding method in the repair business. TIG welding cobalt based superalloys can be done without too much problem. However, the gamma prime strengthened, nickel based alloys used in turbine blading are very difficult to weld. The rest of this section deals only with these alloys.

Welding in a vacuum furnace in a clean atmosphere is necessary to weld the nickel based superalloys in a clean atmosphere. Contamination of the weld pool dramatically increases the incidence of cracking. The argon shield of the TIG torch breaks down when welding complex shapes, so welding takes place in an argon filled glove box. Commercial argon normally has insufficient purity for good welding. The oxygen content of the purging argon has to be specified at less than 10 ppm or recirculating cabinets with built in purifying systems have to be used (fig. 3).

As nickel based superalloys of higher strength were developed so the welding problems increased for two reasons. First the high strength of the material itself and secondly the strength of the weld wire needed to maintain the overall strength of the repaired component.

One problem in welding the precipitation hardened heat resistant nickel based superalloys is due to their strengthening element called gamma prime. The amount of gamma prime in the superalloy and the ease in which it can be solutioned into the material matrix are controlling factors in material weldability (6). Fig. 5 shows how the relationship effects weldability and gives examples of some commonly used super- alloys.

Research has also shown that the thickness of the section to be welded also has an effect on weldability (7). Figure 5 shows the relationship between welding speed and material thickness graphically. As the thickness of the part being welded increases...
Increasing amount of elements influencing diffusion of gamma prime in the material matrix.

Fig. 1 Weldability of Precipitation Hardened Nickel based Superalloys used in Gas Turbines
Area 1 Very Difficult to Weld (Heat Affected Zone cracking. Only weldable at slow speeds).
Area 2 Difficult to Weld (Susceptable to Post Weld Heat Treatment cracking).

so the welding speed must be reduced to obtain crack free welds. It is believed that the reason for this is the increased stresses induced in the material surrounding the weld pool caused by localized shrinkage as the gamma prime precipitates. Whereas with thin material the main shrinkage is the length of the weld, as the material thickness increases so the shrinkage becomes more two directional both in the length of the weld and across its width. With the stresses in two directions cracking is more likely to occur. The main stress directions are assumed to be in the plane of the surface as cracking occurs perpendicular to the surface, not parallel with the welded face as would be evident from significant stresses in this direction. Slower welding speeds reduce the cooling rate allowing the gamma prime to precipitate more slowly and the base material an opportunity to stress relieve itself. As the material thickness increases so it becomes more and more difficult for the welder to reduce his weld speed to the crack free requirements. This relationship between material thickness and weld speed has a significant effect on the repair welding of gamma prime strengthened, nickel based superalloys. Welding on a blade surface is impossible without causing cracks. Thin walled hollow blades are easier to repair than those of a massive section. Welding of pits and cracks on the surface of a blade is not possible without causing further cracks. The damage has to be cut out from the tip or the leading or trailing edge so the weld is applied to an edge and not a surface.

Coupled with the difficulty in the welding of blades is the problem of replacing the missing material with weldments of sufficient strength (10). The strength requirement of the blade material is based on the most highly stressed area of the blade, the root and lower airfoil. The tip of the blade which is not so highly stressed can tolerate a weaker material than the original base material without effecting the overall safety of the component. The strength of the available weld wires has therefore controlled the extent of the repair limit. If a stronger filler wire is used a more highly stressed area lower down the blade can be repaired. The commercially available weld wires first used to repair turbine blades such as In 62, In 625 and Hastelloy W could result in up to a 50% reduction in material properties at high temperature. To increase the strength of the weldments it became obvious that superalloy weld wires would have to be used to obtain comparable material properties to those of the base material. The availability of these weld wires is limited due to considerations such as material purity, difficulty in manufacturing the small diameters required lack of demand and consequent high price. When available the wires create their own problems as they need a far greater control of the welding process if they are to be used successfully. Waspalloy weld wire has been
used for repairing nickel based superalloy blades and repairs utilizing In 738, U 700 and In 100 weld wires are being developed.

At the present time the limit of weld repairing blades utilizing commercially available weld wires together with Hot Isostatic Pressing and Heat Treatments is approximately the top one third of the aero-foil height. This is of course a rule of thumb and varies between different blade designs, materials and usage. To extend the limits further will entail the use of superalloy weld wires and much greater control of the welding process. The control required necessitates the use of automatic welding equipment where the tracking of the TIG torch, wire feed and welding parameters are all computer controlled.

**BRAZING**

High temperature vacuum brazing is an important and sometimes necessary part of the repair process. By controlling temperature gradients during the joining process distortion free repairs can be obtained. This is impossible for welding, where distortion is inherent due to the localised heat input.

The requirements of a braze joint are that it must be strong, oxidation resistant and must not remelt at turbine operating temperatures. To comply with these requirements nickel and cobalt based brazes are used, most of which have a brazing temperature between 1100°C and 1200°C (11). Pure nickel has a melting point of 1455°C so alloying elements, such as boron and silicon are added to lower the melting point to the range mentioned above. When the braze melts and flows into the crack (figure 6) or across a surface as required, the alloying elements partially diffuse into the base material so raising the remelt temperature of the braze. The diffusion of the alloying elements, a temperature and time dependent process, is completed by the time the parts have been heat treated subsequent to the braze process.

The ability to braze a part is very dependent on its cleanliness. The previously mentioned cleaning procedures should be utilized to obtain the optimum surface. The cleaning of tight deep cracks is particularly difficult.

Brassing developments in the repair process have followed two lines. In one direction stronger braze joints were needed for joining materials and filling micro cracks, while in the other superior "wide gap" brazes were needed to build up eroded surfaces.

In the first case the developments in new manufacturing techniques such as diffusion brazes and diffusion bonding (12) have been utilized. While most joints during repair utilize welding, brazing has been used to rebush tie wire holes in turbine blades with success. The diffusion brazes are generally designed to have compositions similar to the base material with better diffusion properties allowing almost completely homogeneous joints after heat treatment.

To build up eroded areas, wide gap brazes have been developed utilizing superalloy powder. By combining superalloy powder with the previously mentioned alloying elements a high strength braze with limited flow properties is produced. Surface layers up to 0.040 inch (1mm) are in regular use while thicker requirements can be met in special circumstances. These layers have similar corrosion and erosion resistance to the superalloy powder used. Therefore the optimum superalloy can be selected for the repair of a particular feature.

Uses of these brazes include the repair of "craze cracking" on nozzles and build up of turbine blades in areas where it is not feasible to weld successfully. "Craze cracking" is the name given to areas that have a network of cracks due to thermal stresses which have then been further eroded by corrosion attack. This damage tends to occur over too large a surface area to allow economical repair by the normal cut out and weld techniques. The build up of foreign object and erosion damage on blade surfaces using the wide gap brazes has been extend to, in one case, the rebuild of the entire blade surface of a set of blades attacked by hot corrosion (13).

**MACHINING**

The requirements of the repair process dictate that a majority of the machining operations are hand controlled. Areas to be repaired, such as stator vanes and blades, are as cast or forged features. Repaired areas are often of limited accessibility, therefore hand held high speed drills are
used to blend repairs. Carbide burrs, grit polishing heads and small belt grinders enable accurate economical reshaping of profiles. To reform hard superalloys by hand takes great skill. During reprofiling gauges are used to ensure the form is within specification.

**Conventional Machining**

Conventional Machining is used to recut blade lengths, slots in nozzle abutment faces, location rails and other features normally machined at new manufacture.

**Electrical Machining**

Unconventional machining methods are also used such as EDM and ECD.

**Electrical Discharge Machining (EDMing)** is used for accurate machining of features, such as trailing edge cooling holes or turbine blade tip hollows and squeelet tips (fig. 7).

**Electro Chemical Drilling (ECD)** is necessary to drill fine deep holes.

In both processes the form of the eroded area is the same as the shape of the electrode. EDM and ECD can be used on electrically conductive materials and provides a faster, cheaper method of machining complex shapes and cooling holes than conventional machining. Indeed conventional machining could not form many of the shapes produced by these processes. The disadvantage of this method of machining on repaired parts is if the electrode touches non metallic deposits, the process stops or the electrode is diverted onto a new path. Non metallic deposits include dirt ingested with the turbine intake air and oxides formed during operation and repair. These contaminants must be removed to enable successful drilling.

**COATINGS**

**Corrosion Preventive**

The requirements of materials used in the turbine section are that they have high temperature strength and corrosion resistance. As higher efficiency is demanded from gas turbines, turbine inlet temperatures rise. The higher the temperature, the more susceptible materials are to corrosion and the more difficult it is to produce a superalloy with its own corrosion resistance (14). Coatings are therefore required to protect superalloy components during operation.

Corrosion and erosion are related. The corrosion attacks the surface of the metal weakening it and leading to erosion by the gas stream and its particulate content. The erosion exposes further base material to corrosion so continuing the cycle and reducing the metal section. This increases the stress in the section, ultimately resulting in failure.

The main elements from which superalloys in industrial gas turbines have to be protected from are Oxygen, Sodium, Sulphur and Vanadium (15). Apart from Vanadium they can all be present in the intake air, but Sodium, Sulphur and Vanadium are particularly prevalent in heavier fuels. Sulphur and Oxygen can combine to attack the base metal at around 700°C giving a practically uniform removal of the material (16). Sodium sulphate on the other hand is extremely aggressive in its molten state at 850°C giving rise to so called Hot Corrosion. Vanadium Oxide also attacks the base material at this temperature. At higher temperatures oxidation is the major form of corrosion.

To counteract these elements, various forms of coating have been devised including Aluminum used together with Platinum or Chromium, Silicon based and MCrALYs. Silicon based coatings are particularly good in the lower to middle temperature ranges, the aluminum based in the middle 850°C temperature range, while the MCrALYs are most effective at middle and higher temperatures (14, 15, 17). No one coating is the answer to all the corrosion problems.

The coatings are of two different categories, dependent on their application, Overlay and Diffusion. Overlay coatings are those where the coating lies on top of the base material. Diffusion coatings sit on the substrate, but also diffuse into it enriching the surface layer.

Overlay coatings are applied by vaporizing or melting the coating constituents by an Electron Beam, Laser, or Plasma flame and then allowing them to deposit on the required surface. The advantage of this process is that coatings with many combinations of materials can be applied. The disadvantages are the possibility of bonding problems and the process tends to be line of sight. The associated equipment is expensive, which increases coating costs.

Diffusion coatings are applied by packing the parts in a box containing the
coating constituents, together with an activator and an inert carrying medium. The parts, surrounded by the powder, are then treated at high temperature to apply the coating and diffuse it into the surface. Although the diffusion process limits the number of materials that can be applied, it is a simple method and produces better bond strengths. (Some overlay coatings are heat treated after application to diffuse the coating into the base material so combining both processes). A disadvantage of the diffusion coating process is that during removal of the coating for repair, the layer of base material into which the coating has diffused must also be removed, so reducing the metal thickness.

Plasma Spraying

Plasma spraying is used in repair to apply various coatings and build up eroded or fretted areas. Original developments in improving the structure of the applied coating centered around increasing the power of the plasma gun to enable the molten material to be projected at higher velocity. Latest ideas are concentrated on spraying the coating in an inert gas atmosphere or partial vacuum. This reduces oxidation of the deposit so increasing integrity. A particularly promising use of this method is in the application of corrosion resistant coating.

A further use of plasma spraying is the application of thermal barrier coatings. These form an insulating layer reducing the substrate temperature. Magnesium Zirconate, a ceramic, is the most commonly used material. Due to the incompatible thermal expansion coefficients of ceramic and metal an inter-layer is used between the ceramic layer and the bond coat to increase integrity (19). Later developments have looked at using yttria to stabilize the coating during thermal cycling (19). Reducing the temperature of the metal increases the life of the component significantly, so the coatings are finding wide spread uses, especially on combustion equipment.

SPECIAL TECHNIQUES

HIPing

Hot Isostatic Pressing (HIPing) is a treatment whereby high pressure and heat are applied to parts to densify them and enable recovery of material properties that cannot be improved by heat treatments only. Typically temperatures of 1200°C and pressures of 100 bar are used. The application of isostatic pressure to the temperature softened material enables the closing of creep voids along grain boundaries, casting porosity and internal micro cracking. Significant improvements can be made in the properties of welds where a superalloy overlay or similar composition to the base material has been used. Conventional braze joint properties can be improved by subsequent HIPing to give diffusion braze quality. The properties of creep prone materials can be completely restored and even improved if HIPed before the creep damage is too great (20).

Whilst being of great benefit to the repair business HIPing is not the answer to every problem. Before HIPing is undertaken, examination of the material should be undertaken to prove its necessity. HIPing cannot cure cracks open to the surface. The purity of the gas used to pressurize the retort has to be controlled or severe oxidation of the material surface can occur. Voids closed by HIPing can be under great stress due to gases compressed within them. As only a minority of repaired items need HIPing, most repair shops do not have sufficient work to fully utilize a HIP unit. There are, however, several specialist companies offering HIPing services to the industry.

Shot Peening

Shot peening is used to enhance the strength of critical areas, such as blade firthree roots. This is done by peening the surface with metal shot so inducing a compressive layer and retarding crack formation. Further work on a shot peened feature either removes the thin effected layer or, in the case of heat treatment stress relieves the surface and reduces the induced compressive force. If it is necessary to shot peen a repaired part to recover its design parameters, this is done after all other processing is complete.

INSPECTION

Throughout repair the conformance of the parts must be controlled. While most parts are rejected from the turbine for repair of cracking found during overhaul, dimensional integrity must also be checked.

Crack Inspection

There are two methods of crack detection commonly used in the repair industry. Penetrant inspection for surface defects and radiography for internal flaws. While many turbine operators use visual dye penetrant for checking components the more sensitive fluorescent penetrant inspection is the method used during repair. (Fig. 8). Both methods use the same principle. In the case of visual dye penetrant inspection
a bright colour indicates the defect. Fluorescent penetrant inspection on the other hand uses the fluorescence of the penetrant when it is exposed to ultra violet light. Skill is required to interpret the results of these inspections and to differentiate between cracks and background indications. Rough surfaces on used components inhibit the effectiveness of the system.

Radiographic inspection is used to inspect for internal flaws. As a general rule, only blades which are more critical components, like X-Rayed. Nozzle guide vanes, which are less highly stressed, can usually be inspected to a sufficient standard using penetrant inspection only. Cracking during operation originates at weak points, generally on the surface, and any internal flaws are limited in size by the section of the material. A realistic X-Ray inspection of a nozzle is also difficult to carry out due to its configuration. Many photographs are needed due to the multiple vanes, hollow forms and varying sections occurring in a nozzle guide vane segment.

Dimensional Inspection
A versatile system of dimensional inspection is needed to enable control of the wide variety of parts most repair shops work on. Besides conventional measuring equipment, gauges are necessary to check the form and position of features.

After repair it is often necessary to recalibrate nozzles to manufacturers specification to ensure correct performance of the machine. From dimensional measurements of the nozzle, the area of the nozzle, and therefore the flow through it, plus the nozzle impulse effect on the blade can be computed. Too large a nozzle area reduces turbine efficiency while blade failure can result from an incorrectly tuned nozzle subjecting blades to irregular impulses. To prevent vibration problems after reassembly of a set of blades on the rotor, a balancing programme is carried out. The moment weight of each blade is measured and from this the position of each blade on the wheel computed. Normal practise for balancing rotors includes balancing individual items, then the assembled rotor and finally the rotor with blades. It is therefore possible to replace a set of balanced blades onto the rotor without effecting the rotor assembly’s balance.

Micrographic Inspection
Micrographic inspection is an extremely important inspection method during repair. Not only must the part be visually inspected, but also the material condition must be analysed. There are no external indications that a material is overaged, or has been over-temperated. It is of little use to repair a part dimensionally if the material is degraded beyond recovery. Based on this information appropriate repair action can be taken.

To undertake an inspection of the micro-structure a small piece of material is removed from a representative part in an area that can later be easily repaired. After mounting, polishing and etching, the structure is inspected under high power microscopes. While 500x magnification is normally used to interpret the micro-structure, 1000x or more is sometimes needed to analyse detail. Comparison is made between the observed structure and standard photographs of the alloy in various conditions. These photographs are obtained from literature supplied by material manufacturers and standard reference works (21). Grain size, undesirable brittle phases such as sigma, carbide precipitation and grain boundary cracking can all be seen and corrective action instigated.

After repair when parts are recoated, metallographic techniques are also used for inspecting the coating. A sample of the same material is run through the coating process with the parts and then cut up and analysed. With a scaled viewer the thickness and integrity of the coating can be determined.

Quality Control
Turbine components are subjected to high temperature and stresses. Failure of a repair could be catastrophic for the turbine. It is therefore necessary to not only inspect a part, but to control its quality at all levels. The Quality Organisation is an integral part of all high technology aerospace manufacturing. As an independent group the Quality Department is able to ensure that the standards set for the production are analysed and met. The repair limits and standards used by the Quality Department are the development of many sources of information. Manufacturers requirements have to be met and some repairs are developed after consultation between the gas turbine builder and the repair source. Some users specify their repair requirements. Various independent bodies are available for testing and advising on repairs such as Research Facilities and Insurance Companies. Joint research projects with manufacturers and other interested parties lead to further understanding of repair. Available parts, both new and operated can be used for reverse engineering exercises. All sources of information are correlated to give realistic standards so maintaining the integrity of the part and the safety of the gas turbine.

Calibration of equipment, definition of acceptance limits, adherence to procedures, assessment of non-conformance and its reduction are all Quality responsibilities. This control enables the customer to get the optimum certified product to fit his requirements.

CONCLUSION
The outlined techniques form the basis of any repair. Conventional and advanced techniques are used, together with technical knowledge of the part, to effect repairs. Work is constantly in progress to refine these techniques and develop new methods therefore improving the repair and extending its limits.
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