TECHNICAL REPORT

VAPOR PHASE ION PROCESSING
FOR MANUFACTURE AND REPAIR OF
GAS TURBINE SUPERALLOY COMPONENTS

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First introduced in 1985 to clean engine run gas turbine superalloy components in preparation for the repair of cracks and other damage by brazing, vapor phase fluoride ion processing has become an indispensable cleaning process for both the manufacture and repair of high temperature gas turbine components. The versatility of the process in allowing complete freedom to adjust the chemical activity control parameters has resulted in a highly reliable process and the development of numerous specific conditions to remove a variety of unwanted scales and contamination without damage to a wide variety of component materials. In addition to cleaning, its usefulness has been extended to stripping a variety of coatings.

Discussion

Gas turbine engines are widely used as power plants for aircraft, marine craft, electrical power generation and pumping stations for petroleum crudes and refined products. The components used in the high temperature sections of these engines are manufactured from sophisticated and costly alloys specially developed to withstand the hostile environment of high temperature, mechanical stress, erosion and oxidation. Additionally, various protective coatings are used to improve component performance and life.

The cost of each component is high – ranging from hundreds of dollars to tens of thousands of dollars each. Although amazingly long lived, the components eventually suffer sufficient damage to require repair or replacement. The damage is typically coating erosion, base material erosion, oxidation, pitting and cracking. Because of the high replacement cost of the components, repair is a cost effective alternative.

Typical repair procedures are as follows: (1) remove the coating, (2) remove all oxides and scales, (3) deep clean cracks and damaged areas, (4) build up eroded areas by welding, (5) fill cracks and surface pits by brazing, (6) restore the component to original size and shape, (7) recoat the component, and (8) certify through various inspections and tests.

In order for the braze repair process as well as some weld repair procedures to be successful, it is necessary to completely remove all scales and oxides including those deeply imbedded in the component surfaces and cracks.

In addition, it is also necessary to deplete the base metal surface of oxide forming elements such as titanium, aluminum and yttrium in order for the braze and weld material to flow into the defects and adhere as well as diffuse into the parent material to form a seamless, flaw free repair. Vapor phase Fluoride Ion Cleaning is the only process which consistently fulfills this requirement. No other method has been successful.

In this process, parts are exposed to flowing high purity hydrogen fluoride (HF) and hydrogen gas at about 1000°C. The fluoride ion reacts with oxides, sulfides, carbides and the metallics (aluminum, titanium, yttrium) to form fluorides. The freed oxygen reacts with the hydrogen to form water vapor. The fluorides and water are swept from the reactor as they are formed. The result is highly cleaned parts which are ready for brazing or welding. Typical cleaned parts are shown in Figure 1.

Because of the ability of the fluoride ion to attack a wide variety of the oxide, nitride and carbide compounds used as protective coatings for gas turbine components and metal working tools, the process use has been extended to the stripping of these coatings for repair. Additionally, it is used to remove manufacturing shop debris, inspection chemicals and contamination from new components prior to coating.

Today, Vapor Phase Fluoride Ion Processing is considered the "Standard of the Industry" and has proven to be an extremely useful and indispensable tool for turbine manufacture and repair.

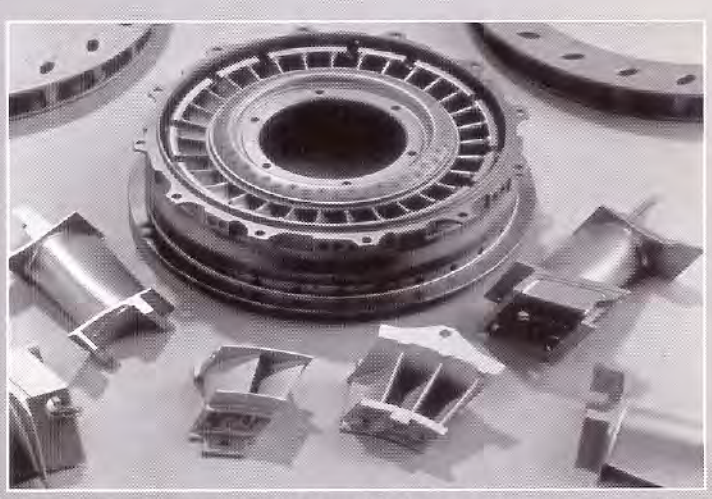


Figure 1. Typical engine run high temperature gas turbine components cleaned by the Vapor Phase Fluoride Ion Cleaning process in preparation for repair by brazing, welding and recoating. Following the repair procedure, components will be returned to useful service.

Background

Braze and weld repair of nickel alloy turbine components was developed under US Air Force Materials Laboratories contract during the 1970's and 1980's. The work was performed by the General Electric Co., Gas Turbine Division at Evendale Ohio. The braze process was based on removing the coating and scales by grit blasting followed by removal of residual oxides using dry hydrogen reduction at 1230° C. then vacuum furnace brazing with specially developed braze alloys. The repair technique, named Activated Diffusion Healing was highly developed, placed into production, and became widely used for military and commercial gas turbine repair.

The cleaning process, called "Hydrogen Bright Annealing", worked well on nickel and cobalt alloys which contained no oxide forming minor elements, so long as the hydrogen was free of nitrogen, methane, oxygen and water. (These contaminants react with the parent material to produce oxide, nitride and carbide surface films which interfere with the braze process.)

However, when the new generation of alloys arrived, which contained aluminum, titanium and yttrium, hydrogen cleaning was no longer adequate since hydrogen does not reduce the oxides of these elements. (These elements form tenacious oxide films that protect the nickel alloy base material from destructive oxidation. This allows engine operating temperatures to be increased over alloys not containing these elements. Increased operating temperature improves engine thermal efficiency and, in turn, engine power output.) Figure 2 shows the results of an attempt to braze repair a crack in a component made of one of these new alloys after hydrogen cleaning. The repair attempt obviously failed. Residual titanium and aluminum oxides prevented the adherence and diffusion of the braze alloy into the parent material. A new cleaning process was needed.

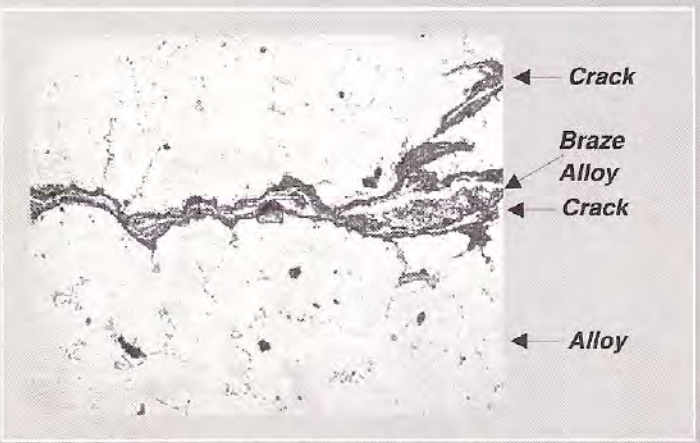


Figure 2. A 200 x magnification view of an attempt to braze repair a crack in a gas turbine nickel alloy containing titanium and aluminum following hydrogen cleaning. The crack appears black due to residual oxides. The braze material (silvery) flowed into the crack but did not wet the surfaces. The repair was obviously not successful.

The Chromous Fluoride Process It was well known from earlier work that fluoride ion at elevated temperature reduces these oxides as well as the other complex oxides formed during engine operation. Wein and Young of General Electric showed that fluoride ion could be released by thermal decomposition of chromous fluoride in the presence of hydrogen at 700° C. and that by placing the turbine components and the chromous fluoride in a reactor, cleaning would result. The process was developed into a production reality and used for several years but was eventually abandoned for the following reasons: Since control of the cleaning process was constrained by the need to precisely control the decomposition of the chromous fluoride, the process produced erratic cleaning results which could not be overcome. It also deposited undesirable porous chrome metal on the parts which required removal by grit blasting following fluoride cleaning. In addition, if the decomposition temperature was not precisely controlled, rapid evolution of gasses could occur which overloaded the exhaust system and caused failure of the retort seals and rapid escape of the hazardous gasses into the furnace room.

The Fluorocarbon Cleaning Process At about the same time, Chasteen of the University of Dayton, under the sponsorship of the US Air Force Materials Laboratory, was successful in cleaning turbine components by exposure to fluoride generated from the decomposition of tetrafluoroethylene in the presence of hydrogen. This process was also developed into a production reality and operated as a service from the University of Dayton. It was later used by several engine component repair centers. The cleaning process variables could not be adequately continued due to the unpredictability of the decomposition process. The results were variable, difficult to control and required two cycles plus thermal vacuum cycles to produce acceptable results. The process was eventually abandoned due to high costs and variable results.

Vapor Phase HF Gas Fluoride Cleaning A third process approach under development by Ti-Coating, Inc. of Utica, Michigan used the direct introduction of HF gas and hydrogen into a high integrity reaction vessel in which the parts were placed around a simple but precise gas distribution systems. Since the gas quantity, component concentration and velocity were controlled external to the reaction vessel, all the process parameters which affected cleaning results could be precisely controlled. Results were consistent, could be optimized for each alloy type and required no post treatment. Placed in production in 1984, the process proved to be cost effective and highly reliable. The technique eventually replaced the other two processes and today is used exclusively in the gas turbine industry. Shown in Figure 3 are turbine vanes before and after cleaning by the Vapor Phase HF Gas Process.

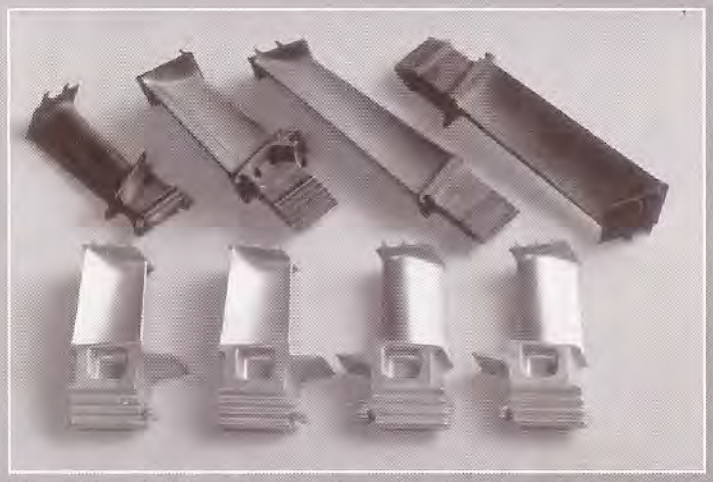


Figure 3. Turbine vanes before cleaning (top row) and after cleaning (bottom row) by HF Gas Fluoride Ion Cleaning. The cleaned parts are ready for braze and/or weld repair.

The microstructure of a properly cleaned engine run gas turbine component ready for braze fill repair of the damaged area is illustrated in Figure 4. Titanium and aluminum depletion in this example is about 12 microns. Accepted practice is to control the depth to between 8 to 30 microns. Depletion is necessary to assure that the braze material wets and diffuses into the parent material. An added benefit of the depleted zone is that the shelf life of the cleaned part is essentially indefinite since no oxide formers are present. The part may be stored in a plastic bag to prevent dust contamination until it can be brazed.

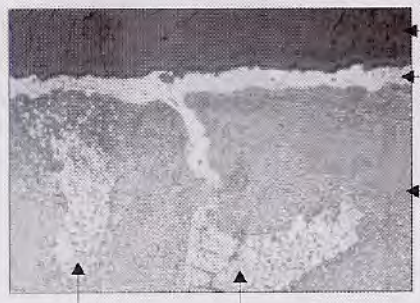


Figure 4. Microstructure of a gas turbine component after cleaning with HF Gas Fluoride Ion Cleaning. Surface and crack areas are completely free of oxides and have been depleted of aluminum and titanium to a depth of about 12 microns (0.0005 inches).

Figure 5 shows the braze repaired crack area of properly cleaned component. Since inception of the process, thousands of turbine components have been repaired by the process and returned to useful service. The detailed procedures and braze alloys used for the repair are generally proprietary but are available through various sources.

Figure 5. Photomicrograph of a braze filled crack area in a gas turbine engine run component following HF Gas Vapor Phase cleaning. Note that the only remaining evidence of the crack is slight acceptable porosity (dark spotty areas about 3 to 8 microns wide).

Process Dynamics

The scales and surface films present on engine run high temperature gas turbine components are composed primarily of complex metal oxides. Sulfides and nitrides are usually also present. At temperatures above 800° C, HF reacts with all oxides, carbides, nitrides, sulfides and carbon to produce fluorides and water. Under static conditions, equilibrium between water and HF concentration is soon reached and the reaction ceases. It is therefore necessary to remove the water from the system as fast as it is produced in order for the fluoride reaction to continue and convert all the compounds present. In addition, most of the fluorides produced are not volatile at the process temperature and under static conditions will remain on the turbine components and stop the cleaning reaction. The solution to both conditions is to operate the process under dynamic (flowing gas) conditions.

In practice, the process is operated between 900° and 1100° C. depending on the component and alloy composition. Hydrogen is added to the HF to achieve an HF concentration of between 5 and 25%. Total gas flow is adjusted to achieve 20 to 25 volume changes per hour. To assure that the fluorides and water are swept from the components, common practice is to alternate gas composition from HF and hydrogen to pure hydrogen several times during the cycle.

Pressure Process Initially, the process was operated at atmospheric pressure using the variables of time, temperature and HF gas concentration to achieve cleaning and the depletion of titanium, aluminum and other oxide forming minor elements. However, as the process was extended to clean deep narrow cracks, it was found that the addition of a pressure step in the cycle forced the HF into the cracks and resulted in cleaning cracks as fine as 12 microns (0.0005 inches).

Vacuum Process Turbine afterburner divergent flaps (see Figure 6) and some turbine blades used on large electrical power generators are prone to develop "craze crack" damage. Repair of the power generator blades was made by grinding the surface to a depth below the cracks. Blades were recoated then placed back into service in the undersize condition. This procedure could not be used for the afterburner flaps since the metal was too thin to allow grinding below the damaged area. A more desirable repair for the power generators and the only potential repair for the afterburner flaps would be to braze fill the cracks.

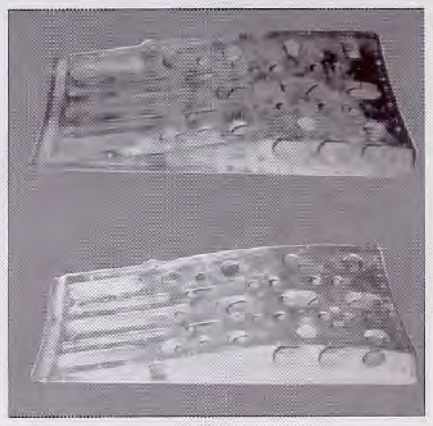


Figure 6. Engine run Afterburner Divergent Flaps suffering craze crack damage. Upper flap is before cleaning. The lower flap is after cleaning with the Vapor Phase HF Gas "Vacuum Pulse" Process. The cleaned part was subsequently successfully repaired by braze filling the craze cracks. Photograph courtesy of The US Air Force, Air Logistics Command, Tinker Air Force Base.

However, the standard cleaning process would not clean cracks sufficiently to produce a sound braze repair. By using alternate vacuum and pressure steps, it was found that the cracks were cleaned and a high quality braze repair resulted. Figure 7 illustrates the improved cleaning achieved by using vacuum to evacuate inactive gases from the cracks, then forcing fresh active gas into the fine cracks followed by vacuum to remove the reaction products. This procedure is now used on a variety of components. The equipment used for the treatment is illustrated

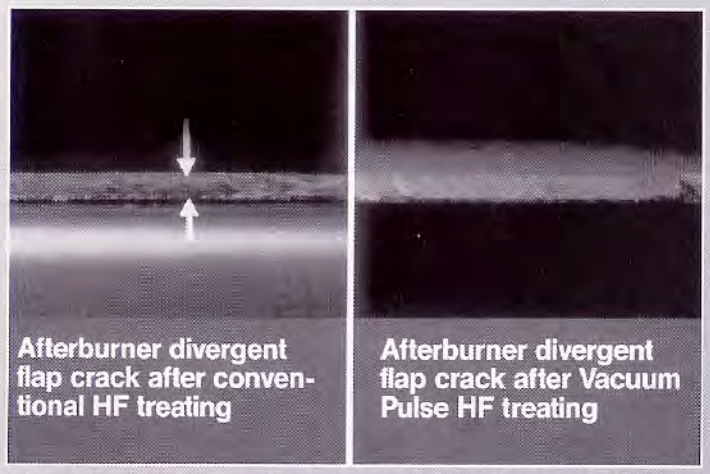


Figure 7. Fracture surface of a craze crack commonly found in afterburner divergent flaps and the companion primary seal flaps from a military jet engine. In the photograph to the left, the component was cleaned using conventional vapor phase HF treating. The grey areas are residual oxides not removed by the treatment. Braze repair of the part was not successful. The component shown in the photograph to the right was cleaned using "Vacuum Pulse" fluoride cleaning. The bright surface indicates the oxide free condition of the part. Braze repair was successful. Today, the primary seal flaps are routinely repaired. The divergent flaps are not being repaired because of economic considerations. Photograph and process results courtesy of The US Air Force, Oklahoma City Air Logistics Command, Tinker Air Force Base.

Fully configured as shown in the schematic, the equipment allows the process flexibility necessary to clean parts under the most demanding conditions. In addition to cleaning surface oxidation, surface pits and wide cracks using atmospheric pressure, part internal passages and fine cracks in the part can be effectively cleaned using one or more special processing conditions. Treating conditions possible are:

1. Flowing gas at atmospheric pressure.
2. Flowing gas at subatmospheric pressure.
3. Static gas at over atmospheric pressure.
4. Static gas at partial pressure.
5. Directing the gas to specific areas by using fixtures.
6. Using hydrogen alone or with any concentration of HF.

All conditions may be incorporated into a single cleaning cycle.

For comparison, the Chromous Fluoride process and the Fluorocarbon process are shown below in Figures 9 and 10.

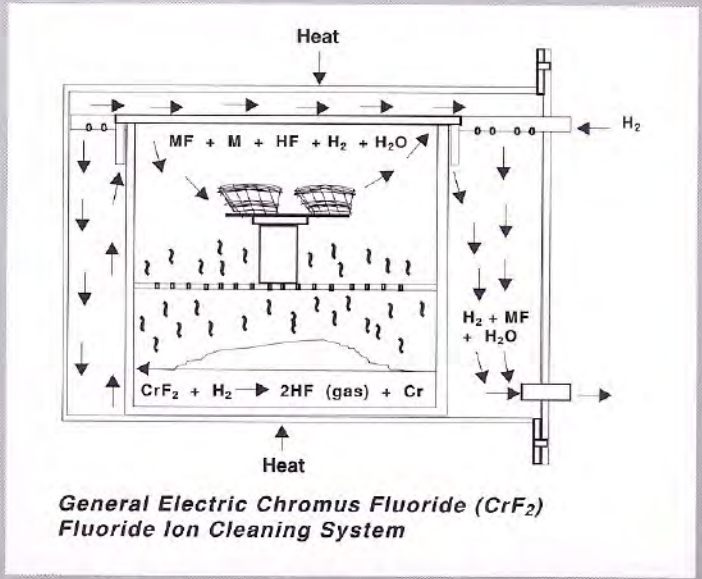


Figure 9. Chromous Fluoride Pack fluoride ion cleaning diagram. Fluoride ion is supplied by decomposition of chromous fluoride at 700° C in the presence of hydrogen.

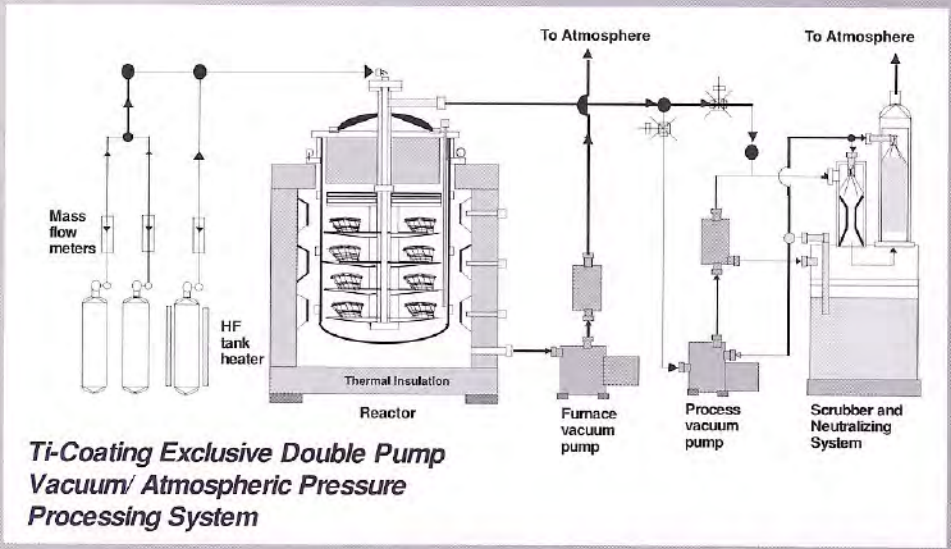


Figure 8. Schematic representation of the HF gas fluoride cleaning system. Precisely metered HF and H_2 gas is distributed uniformly over the parts. Gas composition, treatment time, temperature and pressure (including "vacuum pulse") can be tailored for each alloy component. For vacuum operation, furnace pressure and process pressure control is integrated to effect "0" pressure gradient and minimize stress across the reactor chamber walls.

Chromous Fluoride Decomposition Process shown schematically in Figure 9, illustrates this cleaning technique utilizing relatively simple heat treat equipment. A hydrogen atmosphere retort is heated in an air atmosphere furnace. The process is satisfactory for cleaning surfaces and wide cracks. However, it is necessary to remove residual fluorides and porous powdery chrome metal from the cleaned parts by grit blasting and high temperature vacuum treatment. Constrained by the need to control the decomposition of the chromous fluoride, the process lacks the flexibility needed to optimise the cleaning process.

An earlier version of the process used chrome powder and ammonium fluoride reaction at 250° C to produce the chromous fluoride which, as in the later version, was decomposed to produce the

fluoride ion. After operation for several years, the process was replaced by the simpler and more effective direct chromous fluoride decomposition process.

Fluorocarbon Decomposition

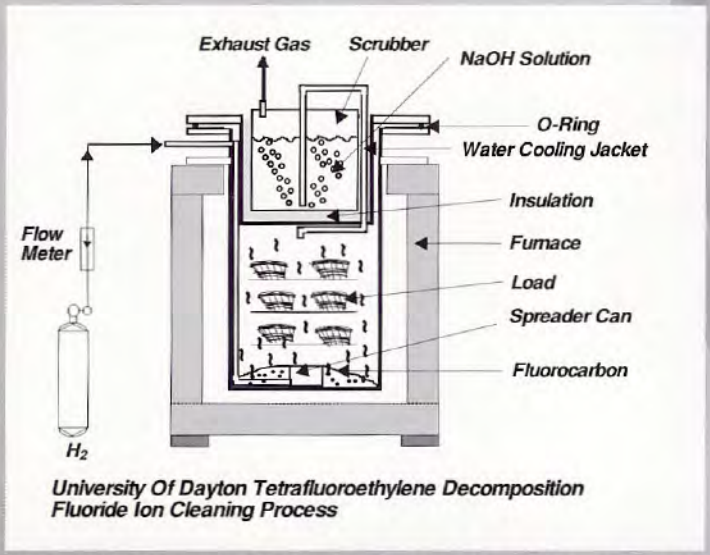


Figure 10. Fluorocarbon decomposition fluoride ion cleaning process schematic. Active C2F4 monomer and HF is produced by the decomposition of tetrafluoroethylene (c2f4polymer).

In this process, C_2F_4 polymer is thermally decomposed to C_2F_4 monomer. The C_2F_4 reacts with oxides to form metal fluorides and carbon monoxide (CO). As the temperature is increased, the C_2F_4 reacts with hydrogen to produce HF and methane (CH_4). The HF is then available to further reduce oxides and produce surface depletion of the titanium and aluminum metals. The CO reacts with water produced by reaction of HF with oxides to produce carbon dioxide (CO_2) and hydrogen.

In principle, this process should be more effective than the HF gas process since water is not available to stop the HF/oxide reaction. However, in practice, the narrow range of decomposition temperatures and side reactions such as the production of free carbon soot plus the inability to add sufficient hydrogen to flush the reaction products from the parts without reducing critical C_2F_4 and HF concentration makes the process difficult to control. In addition, the inability to distribute the gas uniformly over the parts produces erratic results. The process was eventually abandoned in favor of the HF gas process.

HF Gas Process Chemistry

Chemically, the HF Gas process is the metallurgist's dream for cleaning gas turbine high temperature alloys. It attacks and removes unwanted scale compounds while leaving the base metal virtually unscathed. Even the depletion reaction, which is an attack of the base metal, is desirable and controllable to the desired degree. Fluoride ion vigorously attacks the complex oxides, sulfides, and nitrides. which make up the scales and films found on engine run components. Yet, the ion does not attack nickel which is the major metal found in the high temperature gas turbine components. Attack of chrome and cobalt, the other major metals present, is slight. Attack of Aluminum, titanium, yttrium and other oxide forming minor elements, as stated earlier, is vigorous but controllable by the rate of diffusion of the element to the surface of the part.

Many high temperature alloys used in gas turbines and other applications contain iron ranging from less than 1% to as much as 75% in the composition. These alloys are also candidates for fluoride cleaning and repair. Iron oxide is readily reduced by fluoride ion and removed from the component. The metal is easily converted to fluoride. So easily, in fact, that these alloys require special processing conditions to control iron removal. Fortunately, removal is also a function of the rate it diffuses to the surface of the component and therefore can be controlled.

Carbon and carbides are also attacked by the fluoride ion. This reaction is used to remove the carbonatious scales and cokes found on engine run combustion components.

Chemical Reactions The chemical reactions used in the process can be classified as cleaning reactions, surface depletion reactions and alloy depletion reactions. Typical reactions are listed in Figures 11, 12 and 13.

Typical Cleaning Chemical Reactions

$$6HF + Al_2O_3 \rightleftarrows 2AlF_3 + 3H_2O$$
$$4HF + TiO_2 \rightleftarrows TiF_4 + 2H_2O$$
$$6HF + Cr_2O_3 \rightleftarrows 2CrF_3 + 3H_2O$$
$$4HF + NiO_2 \rightleftarrows NiF_4 + 2H_2O$$
$$6HF + Co_2O_3 \rightleftarrows 2CoF_3 + 3H_2O$$
$$6HF + Y_2O_3 \rightleftarrows 2YF_3 + 3H_2O$$
$$4HF + SiO_2 \rightleftarrows SiF_4 + 2H_2O$$
$$6HF + Fe_2O_3 \rightleftarrows 2FeF_3 + 3H_2O$$
$$2HF + FeS \rightleftarrows FeF_2 + H_2S$$
$$4HF + 2C \rightleftarrows C_2F_4 + 2H_2$$

Figure 11. Scale and film removal chemical reactions typical of Fluoride Cleaning. Process is adjusted to maximize these reactions.

Typical Surface Depletion Chemical Reactions

$$3HF + Al \rightarrow AlF_3 + 3/2H_2$$
$$4HF + Ti \rightarrow TiF_4 + 2H_2$$
$$3HF + Y \rightarrow YF + 3/2H_2$$
$$6HF + Y_2O3 \rightleftarrows 2YF_3 + 3H_2O$$

Figure 12. Surface depletion chemical reactions typical of Fluoride Cleaning. Process is adjusted to control depletion to a depth of 10 to 50 microns.

Typical Alloy Depletion Chemical Reactions

$$3HF + Cr \rightleftarrows CrF_3 + 3/2H_2$$
$$3HF + Co \rightleftarrows CoF_3 + 3/2H_2$$
$$3HF + Fe \rightleftarrows FeF_3 + 3/2H_2$$

Figure 13. Alloy depletion chemical reactions typical of Fluoride Cleaning. Process is adjusted to minimize these reactions.

The Effect of Water All the chemical reactions involving oxides produce water as a reaction product. Since the reactions are reversible, the process can only be successful if the water is

removed from the system as fast as it is formed. This is accomplished by adjusting the total gas flow to sweep the water and other reaction products from the reactor as they are formed.

Introduction of water into the system from contaminated gas supplies or by aspiration of atmospheric air through leaks in the plumbing or seals must be avoided. This is accomplished by limiting water and oxygen contamination of the hydrogen to 10 ppm maximum while limiting the moisture content of the HF to 3 ppm. Bulk quantities of high purity gases are readily available commercially. Leaks are controlled by using high integrity plumbing, components and seals plus routinely performing integrity checks. Atmospheric air and the water it contains is excluded from the process by performing purges with dry argon prior to each cycle, and by sealing the system under argon when not in use.

Handling HF The highly corrosive character of HF when combined with even minute quantities of water means that a special handling system is necessary. Even so, it is successfully handled and used in many industrial processes. The article to the right describes how the HF is handled for the process discussed here.

Process Applications

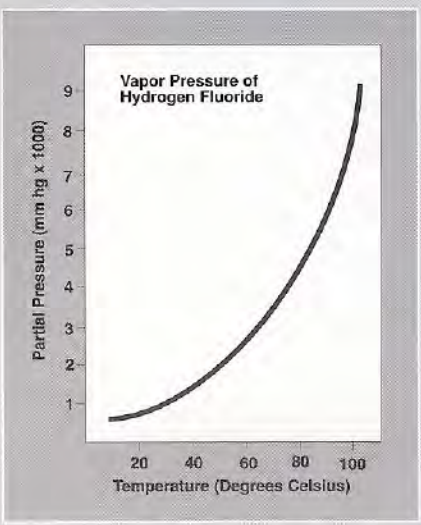
Since inception, the HF gas fluoride ion process has been extended to perform many useful functions in the manufacture and repair of gas turbine engines. The most useful and widely used function is to clean aircraft gas turbine engine hot section components for braze and weld repair. An accepted industry standard, the process has been refined and parameters adjusted to clean a wide variety of alloys and components. A listing of the alloys and components successfully prepared are given in tables 1 and 2.

With the proliferation of gas turbines for use in electrical power generation, other stationary power uses and ship propulsion, there is a growing need to refurbish these engines. Fluoride Ion cleaning is now being used in the repair of a growing list of components in this class of turbines. Several systems are now operating exclusively in this industry.

HF Delivery: Special Handling Required

Dry HF is relatively inactive chemically at low temperatures and can be handled quite safely. However, when combined with water it instantly becomes highly corrosive hydrofluoric acid. This acid reacts with almost everything in sight except for a few materials such as high nickel containing alloys. It can cause severe burns to the skin and, if breathed, can cause severe lung damage. Handling HF successfully and safely dictates reliable containment to exclude any moisture contamination of the supply or release of HF to the surroundings. A safety backup system is desirable should the containment fail.

HF is a liquid at room temperature. As the temperature is increased to about 40°C, the liquid becomes a gas with sufficient pressure to be delivered and metered into the reactor. As HF vaporizes, it becomes a polymer composed of several HF molecules. As the temperature increases, it de-polymerizes eventually becoming a monomer of one HF molecule. This fact accounts for the unusual shape of the vapor pressure curve (see graph). Successfully metering the gas at low temperature requires precise temperature control to stabilize the mass of the gas and a specially designed mass flow controller.



HF: Unusual vapor pressue requires special control equipment.

The vapor pressure curve also shows that limiting the HF temperature will minimize pressure and hence, reduce the escape of gas into the atmosphere should a leak occur.

The HF handling system used in the Ti-Coating equipment addresses the above noted criteria by using an enclosed cabinet to house the HF supply tanks and all ancillary systems. Detectors, sensitive to 1 ppm, are provided in the cabinet and in the facility to detect any release of HF.

The HF supply tanks are heated with temperature controlled water jackets to the prescribed temperature for metering and introduction into the reactor vessel. A separate cold water supply is incorporated into the circuit which allows the tanks to be quickly cooled and the gas pressure reduced should HF be detected in the cabinet or elsewhere in the facility. Reducing the pressure, of course, limits or may even stop the release of HF. Also, using water as the heating medium limits the maximum pressure the HF can reach to the vapor pressure corresponding to 100° C. should the heating elements fail in the on position.

An ammonia gas supply and circuitry is also incorporated into the system as a backup system. Should HF be detected, the ammonia is automatically released into the cabinet to neutralize any release of HF. An argon gas circuit is provided to purge the HF from the plumbing when not in use or before maintenance is performed.

High integrity stainless steel piping, fittings with "O" ring seals, and bellows seal valves are used throughout the system to minimize the chance to contaminate the HF supply or for leaks and corrosion to develop. Finally, all switching and control functions are supervised, sequenced and controlled by the system central control for fully automatic operation.

The system, now in operation since 1985 and in over 30 units world-wide has proven to be precise and reliable. It has become the standard method for handling HF and other hazardous chemicals requiring vaporization for use in other vapor phase processes such as chemical vapor deposition.

Table I
High Temperature Alloys
Successfully Prepared for Braze Repair by HF Gas Fluoride Ion Cleaning

	Nominal Composition														
Alloy	**Ni**	**Cr**	**Co**	**C**	**Fe**	**Ti**	**Al**	**Mo**	**W**	**Mn**	**Si**	**B**	**Zr**	**Cb/Ta**	**Other**
FSX-418	10.50	29.5	51.04	0.250	1.00	-	-	-	7	0.50	0.05	0.0120	-	-	Y .15
HAYNES 188	22.00	22.0	38.84	0.100	1.50	-	-	-	14.50.63		0.35	0.0075	-	-	La .075
Mar-M-509, (PWA 647)	10.00	23.4	54.80	0.600	-	0.2	-	-	7	-	-	-	0.50	-	Ta 3.5
STELLITE 31, (X-40)	10.50	25.5	53.50	0.500	1.50	-	-	-	7.5	0.50	0.50	-	-	-	-
WI-52 PWA (653)	0.50	21.0	63.55	0.450	1.50	-	-	-	11.0	-	-	-	-	2.00	-
17-4PH S/S	4.10	16.1	-	-	76.40	-	-	-	-	-	-	-	-	0.28	Cu 3.15
310 S/S	20.50	25.0	-	0.250	50.67	-	-	-	-	2.00	1.50	-	-	-	P .045, S .03
321 S/S	10.50 1	8.0	-	0.080	67.84	0.5	-	-	-	2.00	1.00	-	-	-	P .045, S .03
347 S/S	10.50	18.0	-	0.080	67.54	-	-	-	-	2.00	1.00	-	-	0.80	P .045, S .03
A-286	25.50	15.0	-	-	55.14	2.1	- 1	.25	-	-	-	0.006	-	-	Cb 1.0
MA-956	-	20.0	-	-	74.50	0.5	4.5	-	-	-	-	-	-	-	Y_2O_3 0.5
B-1900+Hf, (PWA 1455)	63.39	8.0	10.00	0.110	-	1.0	6.0	6.00	-	-	-	0.015	0.08	-	Hf 1.15, Ta 4.25
B-1900, (PWA 663)	64.50	8.0	10.00	0.110	-	1.0	6.0	6.00	-	-	-	0.015	0.07	-	Ta 4.3
C 101	59.43	12.6	9.00	0.090	-	4.0	3.4	1.90	4.0	-	-	0.015	0.06	-	Hf .90, Ta 4.3
C 1023	58.45	15.5	9.70	0.150	-	3.6	4.2	8.40	-	-	-	-	-	-	-
C 242	59.20	20.0	10.00	0.300	0.50	-	-	10.00	-	-	-	-	-	-	-
CMSX3	66.36	7.8	4.60	-	-	1.0	5.6	0.50	8.5	-	-	-	-	-	Hf .14, Ta 6.0
HASTELLOY C	54.90	17.0	-	0.100	6.00	-	-	17.00	5.0	-	-	-	-	-	-
HASTELLOY S	65.92	15.8	0.01	0.010	1.50	-	0.3	15.20	-	0.70	0.50	0.010	-	-	La .05
HASTELLOY X	47.40	22.0	1.50	0.100	18.50	-	-	9.00	0.5	0.50	0.50	-	-	-	-
IN-100	60.74	9.5	15.00	0.180	-	5.0	5.5	3.00	-	-	-	0.015	0.06	-	V 1.0
IN-738	61.48	16.0	8.50	0.130	-	3.4	3.4	1.75	2.6	-	-	0.012	0.12	2.60	-
IN-792	60.86	12.2	9.00	0.120	-	4.1	3.5	1.90	3.8	-	-	0.015	0.10	-	Hf 0.5, Ta 3.9
INCONEL 600	72.79	15.5	-	0.150	8.50	-	-	-	-	0.50	-	-	-	2.30	Cu .25, S .008
INCONEL 713C, (PWA 655)	72.77	1.5	-	0.140	-	0.9	6.0	4.50	-	-	-	0.010	0.08	2.10	-
INCONEL 713LC	74.64	12.0	-	0.050	-	0.7	6.0	4.50	-	-	-	0.010	0.10	-	Cb 2.0
INCONEL 718	52.48	19.0	-	0.050	18.50	0.9	0.6	3.00	-	0.18	0.18	-	-	5.10	S .008
INCONEL X-750	71.73	16.0	0.50	0.040	7.00	2.5	0.7	-	-	0.05	0.25	-	-	-	Cu .25, Nb .95, S .025
MA-754	78.56	20.0	-	0.040	-	0.5	0.3	-	-	-	-	-	-	-	Y_2O_3 .60
MAR-M-200+Hf (PWA 1422)	57.59	9.0	10.00	0.140	0.75	2.0	0.5	-	12.5	-	-	0.015	-	-	Cb 1.0, Hf 2.0
MAR-M-247 (PWA 1447)	59.63	8.4	10.00	0.150	-	1.1	5.5	0.65	10.0	-	-	0.015	0.055	-	Hf 1.4, Ta 3.1
PA101	60.00	12.6	9.00	-	-	4.0	3.4	1.90	4.0	-	-	-	-	-	Hf 1.0, Ta 4.1
PWA 1035	98.00	-	-	-	-	-	-	-	-	-	-	-	-	-	ThO_2 2.0
RENE 125	59.03	9.0	10.00	0.100	-	2.6	4.8	2.00	7.0	-	-	0.015	0.050	-	Hf 1.6, Ta 3.8

Brazing New Parts Some engine components consist of dissimilar alloys joined by brazing. Components consisting of thin and thick sections are also joined by brazing. Achieving a brazeable interface has long been difficult because of surface oxidation. The practice has been to nickel plate the components to improve brazeability. The plating procedure is costly and it is difficult to achieve the quality required. Eliminating the nickel plating and using fluoride ion cleaning to produce brazeable surfaces is now being used on many of these components.

Aluminide Coating of New Parts As improved engine performance has evolved so has the need for improved aluminide diffusion coatings. Fluoride ion cleaning prior to coating removes shop dust, oxides and inspection chemicals from the part surface thereby enhancing the coating process, minimizing interface imperfections and enhancing the diffusion process to produce a higher quality coating with improved performance.

Chemical Vapor Deposition Because of the capability to produce aluminide coatings with dopants such as silicon by chemical vapor deposition (CVD), many turbine components are being coated with this process. Another advantage of the CVD process is that fluoride ion capability can easily be added to a system and a cleaning step incorporated in the coating cycle. Several HF/CVD systems are now used in production.

Table II
Gas Turbine Engine Components Successfully Prepared for Weld and/or Braze Repair by HF Gas Fluoride Ion Cleaning

Air Swirlers	LPT Nozzles
Bearing Support Covers	Nozzle Segments
Bearing Supports	Outer Air Seals
Burner Cans	Rotors
IGT Buckets/Blades	Shroud Housings
Combustion Liners	Deswirls
Shroud Hub Assemblies	Shrouds
Divergent Flaps	Stator Housings
Ejector Nozzle Segments	Stators
Engine Cases	Vane Segments
Fuel Nozzles	Vanes
HPT Nozzles	

Thermal Barrier Coatings The primary thermal barrier coating used today to protect engine hot section components is composed of yttria stabilized zirconia (ZrO_2/Y_2O_3). The fluoride ion readily attacks this oxide. The HF Gas Fluoride Ion Process is now being used for

stripping this coating from components and fixtures. Shown in Figure 14 are test sections cut from a coated combustion liner illustrating the samples before and after stripping.

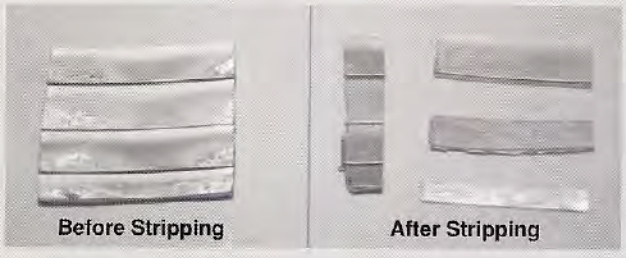


Figure 14. Photograph of test samples taken from a combustion liner coated with ZrO_2/Y_2O_3 thermal barrier coating. The coating was removed by fluoride ion processing without attack of the base metal.

Combustion Components Engine run combustion components are usually covered with heavy oxide, nitride, sulfide and carbonatious coke scales which must be removed prior to repair. The fluoride ion process readily removes these compounds. The photographs in Figure 15 illustrate the bright appearance and absent of combustion products after cleaning.

Figure 15. Photograph of a combustion liner with first stage turbine vanes shown prior and after cleaning by HF Gas Fluoride Ion. After cleaning, the components will be repaired by brazing and/or welding. Note the characteristic bright appearance of the cleaned components.

Tool Wear Resistant Coatings Metal working tools (cutting and forming) are coated with a variety of carbide, nitride and oxide compounds which enhance the tool performance. The class of tools composed of tungsten carbide and cobalt are costly, can withstand the temperature required for the fluoride ion process and are therefore candidates for stripping. In practice, stripping is used in two ways. Tools with defective coatings caused by the manufacturing process are stripped and recoated. Certain used tools can be stripped, reground and recoated. In Figure 16, carbide tools are shown before and after stripping along with turbine vanes before and after cleaning.

Turbine Aluminide Diffusion Coatings Prior to weld or braze repair, it is necessary to strip the aluminide diffusion coatings common on turbine components. (Actually composed of nickel aluminide.) Current practice is to strip the coatings using acid chemical solutions. Handling the hazardous solutions is difficult and disposing of the wastes also difficult and costly. Tests have shown that the fluoride ion process can be adjusted to remove the aluminum component of the coating while leaving the nickel component intact as a skeletal structure on the component surface which does not interfere with the repair process. After repair, the component can be recoated by standard aluminide processes to restore the original nickel aluminide coating. This technique is seen as advantageous in that the nickel remains with the component as opposed to becoming a part of the chemical stripping solutions and the associated disposal costs. Illustrated in Figure 17 is the result of exposing a typical aluminide coating to the fluoride ion process.

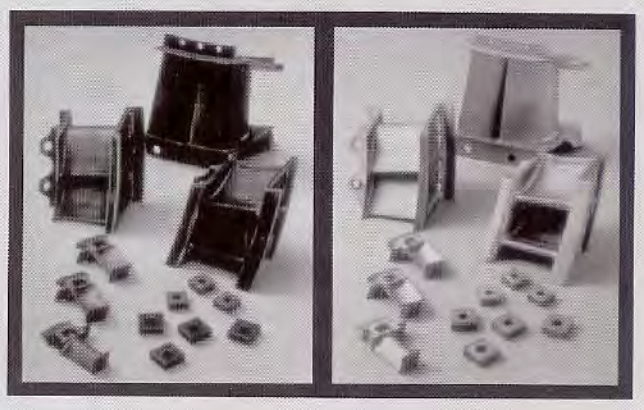


Figure 16. Carbide tools and turbine vanes before (left) and after (right) fluoride ion processing. Carbide tools were stripped of wear resistant coatings. Vanes were cleaned for subsequent braze repair.

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