

# Successful Applications for TEC X-Ray Diffraction Analysis

## Overview

TEC's portable x-ray diffraction analysis systems are being used by both TEC customers and TEC technicians in the Materials Testing Laboratory to solve a number of failure analysis, quality control, and process control problems in aerospace, automotive, and materials

R&D applications. Through the use of these systems for residual stress and retained austenite analysis, customers have been able to prevent or predict component failures, improve component reliability and life, improve manufacturing yield, and understand the effects of materials processing.

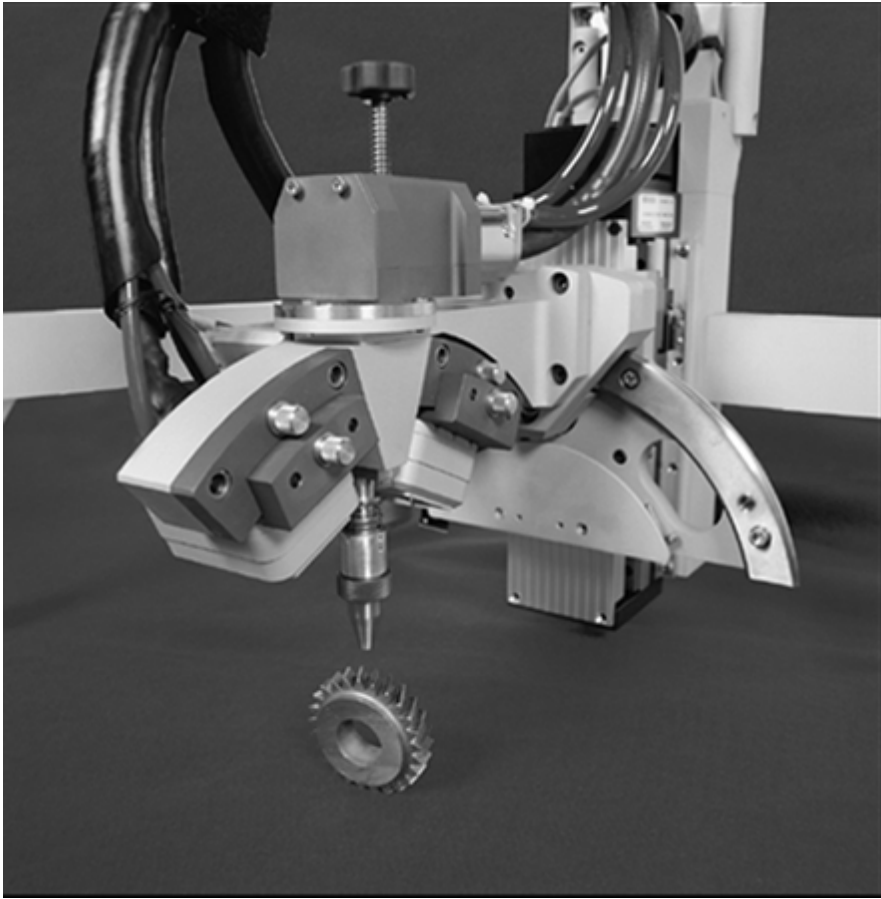
Several of these successful applications are described in the following sections:

### Technical Benefits

### Applications Experience

- Airframe Components
- Automotive Components
- Turbine Engine Components
- Utility Applications

The TEC 4000 X-Ray Diffraction System for Residual Stress and Retained Austenite Analysis



TEC's Materials Testing Laboratory Services are



## **Measurements of Stress by X-Ray Diffraction**

### **Technical Benefits**

#### ***Speed and Ease of Operation***

Many customers have told us that they have needs for residual stress analysis and that they have an x-ray diffraction laboratory, but they do not use it because it takes up to eight hours to perform a single stress measurement.

The TEC 4000 X-Ray Diffraction Analysis System has been designed for easy setup, easy operation and high-speed automated data acquisition and analysis to permit high levels of productivity for the user. This user-friendly system requires minimal knowledge of x-ray diffraction analysis or computer operation in order to produce reliable, repeatable data.

Conventional diffractometers require that large or irregularly shaped components be cut up into small pieces for analysis. These same components can be analyzed undamaged by the TEC portable diffractometer with a minimum of setup or jiggling.

#### ***Flexibility***

The TEC 4000 X-Ray Diffraction Analysis System is designed to quickly analyze a wide range of materials in complicated configurations. The materials analyzed by our customers or in our applications laboratory include austenitic, ferritic, and martensitic stainless steels, aluminum, alumina, carbon steels, alloy steels, copper,

brass, nickel, nickel alloys, titanium alloys, cast iron, depleted uranium, tin, chromium, alpha iron, silicon carbide, silicon nitride, and tungsten carbide. The design of the diffractometer permits changing of pre-aligned x-ray tubes in less than 15 minutes when required for different materials.

TEC also offers automated retained austenite analysis. This analysis, used with residual stress analysis, is used as a quality control measure in steel heat-treated components.

#### ***Portability***

The TEC portable diffractometer permits analysis of samples ranging from high pressure turbine blades to entire engine mounting frames, from tensile test specimens to airplane wings, and from bearings to engine blocks. The noncontact, nondestructive analysis provides an excellent method of process and quality control in a wide variety of metal processing applications.

#### ***Safety***

The TEC 4000 X-Ray Diffraction Analysis System utilizes a low-power x-ray source ( $\leq 30\text{kV}$ ,  $\leq 6.7\text{mA}$ ) and a highly sensitive position sensitive proportional counter. The TEC Stress Analyzer was designed using the guidelines contained in NBS Handbook 111, also known as ANSI Standard N43.2 "Radiation Safety for x-ray Diffraction and Fluorescence Analysis Equipment". The requirements for an open-beam x-ray system listed in this standard are met by the TEC system.



### Applications Experience

#### Airframe Components

##### 1. Landing Gears:

Many landing gear pistons and cylinders are made from high-strength steel (300M or 4340). This material is very susceptible to hydrogen embrittlement and stress corrosion cracking, unless the surface is in high compressive stress.

TEC X-Ray Diffraction Analysis Systems are being used to evaluate landing gear stresses that can be the indicator of impending failure. It is important to know if any areas of low compressive, or, tensile stress exist in the gear surface. In fact, a gear can crack in the plating bath from hydrogen embrittlement if tensile stresses exist in the part. Since crack growth in these materials is often very rapid, failures can occur on aircraft between inspection intervals. An on aircraft failure often results in substantial aircraft damage. Tensile stresses can be caused by fatigue damage in service, abusive machining in rework, grinding burn, or improper fixturing while machining. Landing gears can be evaluated during overhaul to determine tensile stress states that can lead to failure.

##### 2. Aircraft Skins:

X-ray diffraction analysis is being used in two important areas to evaluate the quality of aircraft skins. The effects of the use of plastic bead and agricultural media blasting for paint removal and the compressive stress field around cold worked holes have been evaluated. Because of the environmental problems associated with solvent removal of paint on aircraft, plastic bead and agricultural media blasting is being used to remove paint without the environmental problems. Recently, however, maintenance operations are starting to look at the effects of this blasting on skin fatigue life. Some tests have been conducted which indicate a substantial reduction in fatigue life as a result of

this blasting. Residual stress analysis indicates a very high, superficial residual stress is being induced by this blasting with depth somewhat affected by intensity. This compressive stress layer has caused skin warpage. Also, it is believed that if the compressive layer does not penetrate below a surface defect, this defect is more likely to be a crack initiation site. The work completed so far indicates that a thorough residual stress analysis should be performed before widespread use of any surface modification process.

The mechanical expansion of holes in skins has been proven to improve the fatigue life of the skin by reducing crack initiation around the holes. X-ray diffraction analysis can be used to verify that holes have been properly cold worked. The measured residual stresses around cold-worked holes are very close to the values predicted by engineering analysis. The TEC 4000 X-Ray Diffraction Analysis System can quickly and nondestructively verify that holes have been correctly cold worked in critical areas.

##### 3. Structural Members:

X-ray diffraction analysis is being used as a general failure analysis tool to understand problems in aircraft structures. Stress analysis can aid in determining the cause of a failure and in changing the process to correct the problem.

##### 4. Nickel Plated Components:

A common technique of repairing steel aircraft components is to machine a damaged surface, build up with nickel plating, and grind or machine back to original specifications. The fatigue life of the repaired component is a function of the plating and machining or grinding process. Extensive analysis work has been performed on nickel plated mechanical test specimens with different plating, machining, and grinding conditions. The data indicate that machining of the plated area produces compressive stresses and increases fatigue life of the specimen.



## **Measurements of Stress by X-Ray Diffraction**

### **Automotive Components**

#### **1. Engine Components:**

TEC X-Ray Diffraction Analysis Systems are being used for statistical quality control of engine components. This work includes evaluation of crank shafts for grinding burn, rods for compressive depth from shot peening, and case depth analysis of carburized and nitrided parts. Retained austenite is also being analyzed in heat treated parts with the systems.

#### **2. Bearings:**

Control of the entire manufacturing process is important to the manufacturing of a quality bearing. Residual stress analysis of the raw steel stock through finished product provides cost effective process control. Factors that affect quality are case depth, grinding burn, surface stress, plastic deformation, and retained austenite. The TEC 4000 X-Ray Diffraction Analysis System can provide all of this analysis quickly and reliably.

#### **3. Wheels:**

Beneficial compressive residual stresses are being built into steel automotive wheels to permit weight reduction without decreasing life or performance. The TEC X-Ray Diffraction Analysis Systems has been used to verify that the stresses predicted by computer modeling are actually in the wheel.

#### **4. Leaf Springs:**

Truck leaf springs are typically formed, heat treated, and shot peened. In order to provide the proper arc, a final "bumping" is performed. Evaluation of field failures indicated that failures were occurring in the region where the bumping occurred. X-ray residual stress analysis indicated that the surface stresses were tensile in the bumped areas and compressive on the rest of the spring. This analysis indicated that shot peening should be performed after bumping to leave the entire surface compressive to reduce spring failures.

### **Turbine Engine Components**

#### **1. Diffuser Housings and Plenums:**

Analysis of Inconel 718 in the areas near welded bosses was performed to evaluate the tensile stresses associated with welding and the effects of shot peening in the weld area. This area is critical because the fuel lines attached to the bosses load the part. Compressive stresses are important to prevent cracking in this area.

#### **2. Compressor and Fan Blades:**

Titanium compressor and fan blades are being weld repaired in noncritical areas to remove FOD (Foreign Object Damage). The repair consists of electron beam weld of new titanium to the blade, or a multipass weld to deposit titanium into the repair area. Stress analysis was performed on both types of repair after blending and after glass beading or shot peening. The residual stress after blending was low, and after peening was comparable with new blades. This stress analysis showed that the repaired blades had the same surface stresses as new blades after peening.

Stress analysis has been performed on new and run fan blades to correlate surface residual stresses with life. Preliminary work indicates that residual stress decreases with run time. Additional work is planned to determine if surface residual stresses can be used as an indicator of remaining useful life in titanium fan and compressor blades. This has the potential for significant cost savings, since fan blades are very expensive.

Titanium fan blades have been analyzed for residual stress versus depth to determine optimum shot peening parameters. The depth profile in titanium is very important to fatigue life. It is desirable to have as deep a layer as possible of compressive stress to minimize the effects of FOD. However, over peening to increase the depth of compressive stress can cause a tensile spike under the compressive layer. This can cause subsurface crack initiation which is undetectable by conventional NDT



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## **Measurements of Stress by X-Ray Diffraction**

inspections. Residual stress analysis is being used to optimize peening intensity to prevent this tensile spike.

### **3. Compressor Disks:**

Inconel 718 compressor disks have been analyzed to determine residual stresses generated in fabrication that cause part distortion. The TEC system allowed analysis of the entire disk assembly, where sectioning had been required for laboratory analysis. Sectioning relieves some of the important residual stresses, therefore use of the TEC system provided for a more complete analysis of the disk.

### **4. Bearings:**

Turbine engine bearings are often reground and reused in turbine engines. In order to ensure a quality bearing, it is important to know that the bearing races removed from an engine are repairable and that the regrind process does not burn the races. X-ray residual stress analysis used along with conventional techniques provides a more complete evaluation of the grinding process and of final bearing quality.

## **Utility Applications**

### **1. Heat Exchanger U-Bend Tubes:**

Austenitic stainless steel tubing is often bent into U-shapes for use in heat exchangers. It is important to verify that the bends in these tubes have been stress relieved to minimize stress corrosion cracking.

Developing techniques for nickel plating analysis allow the TEC 4000 X-Ray Diffraction Analysis System to nondestructively determine if the residual stress has been relieved below the  $\pm 5$  ksi requirement. Previously, this could only be done destructively by strain gaging and sectioning or blind hole drilling.

### **2. Steam Turbine Analysis:**

Turbine disks have been analyzed with a TEC X-Ray Diffraction Analysis System taken into the field to determine surface residual stresses after some stress corrosion cracking was noted on a disk. Analysis indicated that one disk had high compressive stress, while the other had tensile stresses.

