HIGH RESOLUTION COMPUTED TOMOGRAPHY IMAGING FOR MATERIAL CHARACTERIZATION

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INTRODUCTION

With the advancement of aerospace components and structures, traditional materials do not possess the capabilities to perform at the anticipated mechanical stress levels for future generation aerospace applications. New and complex materials are being continually being developed to meet the evolving requirements of these applications. Complicated processes that create these developmental materials are delicate and intricate, making characterization information of the material and/or the process valuable data to material development community. This information may enable the designer to determine whether the material is properly made, the expected range of performance based on the material quality, and anticipate adjustments in future material processing parameters.

Nondestructive evaluation (NDE) is the integral key to enabling this process. In the development cycle of a new or advanced material, the predominant area of interest is correlating the process development parameters with the performance of the material. This type of correlation requires in-depth information of the process as well as detailed information of the material, typically at the microscopic level. Traditionally, microscopic examinations have been performed following the destructive sectioning of the material. Unfortunately, in this process, the specimen is destroyed, preventing any further examination and possibly causing damage that can warp the findings. In recent years, the innovative capability to nondestructively image the interior of a material, with high resolution using X-ray Computed Tomography (CT), has been mastered. A high resolution X-ray CT system called Tomoscope was one of the

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original "microscopic"-CT systems developed specifically for the examination of small coupon size samples of new emerging materials. This Air Force system was installed in the Wright Laboratory, Materials Directorate, X-Ray Computed Tomography Research Facility in 1990.

SYSTEM DESCRIPTION

The Tomoscope CT system, TOMO for short, is a unique machine that allows the nondestructive imaging of the interior structure of new and advanced materials and components. A photograph of TOMO is shown in Figure 1. The system is made up of a prototype 200kV source, with a focal spot typically 35 micrometers, and a fiber optic detector system, with 25 micrometer detectability, in a third generation, rotate only data acquisition design. The unique source and detector systems allow for an optimum spatial resolution of 25 micrometers. With this tight spatial resolution, the field of view has been limited to 100 mm to minimize the source to detector distance. Currently the optimum 35-50 micrometer resolution advances analysis of materials that heretofore have been a mystery. Future hardware improvements are currently being procured to further capitalize on the potential of this machine. The primary focus of examinations will be to assist design engineers in the characterization of the new and advanced materials that are in the early stages of development.

TOMO has been used to examine a variety of materials and products. This paper will present some examples of CT imaging as a nondestructive tool that has helped characterize new materials and evaluate new material processes. The following examples represent a wide cross section of materials, processes and applications.

METAL MATRIX COMPOSITE

Metal Matrix Composite (MMC) materials are the advanced, high temperature, high performance materials of the next generation of aerospace systems. The effects of defects within this material will be critical to the ultimate performance of the components and ultimately, the overall system.

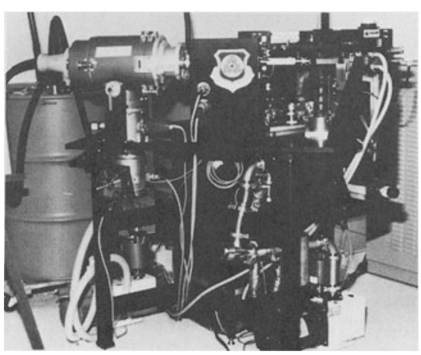

Figure 1. Tomoscope CT System at Wright-Patterson Air Force Base.

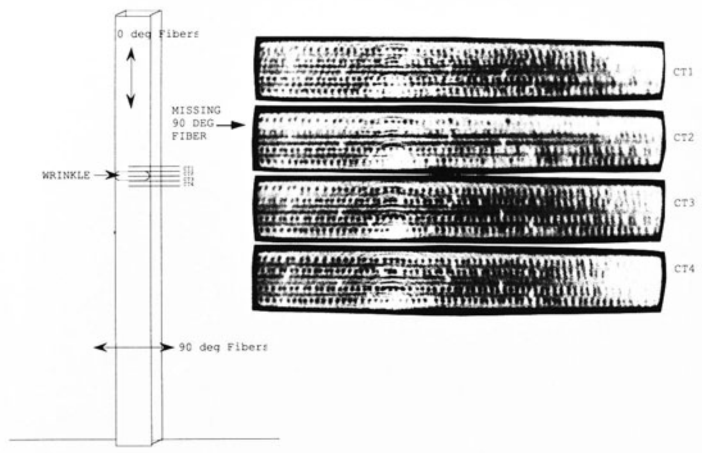

Figure 2. Scan locations and CT images of metal-matrix composite specimen with wrinkle.

A material specimen was received at the Tomoscope CT facility that was titanium matrix with 150 micrometer fibers in an alternating 0 deg/90 deg 8-ply layup. The flat panel specimen measured 100 mm in length and 12 mm in width. Across the width of this specimen was a "linear" depression in the surface of the material, a wrinkle. To assist the materials engineers in the study of this new material and the determination of the cause of the wrinkle in this specimen, four contiguous CT slices were taken that fully examined the wrinkle area.

Figure 2 shows the scan plan on the left and the corresponding four CT slices on the right. A fiber, in the orientation matching that of the wrinkle, is missing from the specimen at the midpoint of the wrinkle. As the strength and performance of this material is directly dependent upon the placement of the fibers in the layup, a missing fiber could be detrimental to this specimen and significantly effect the material's properties. CT has afforded the design engineers the opportunity to examine the interior of the material prior to any structural testing and destructive analysis.

TURBINE BLADE

Turbine Blades are an evolving technology for the future aerospace engine systems. Blades must be lighter weight, but capable of higher temperatures and larger stresses than in the past. Many new systems are seeking out new materials to match the above list of criteria. Some are advancing the manufacturing process of existing designs in an attempt to economize for the next generation systems.

Figure 3. is a CT image of a small nickel alloy turbine blade. Though an old blade design, this inspection demonstrated the capability of the high resolution TOMO in examining the interior of the part. Once cast, these blades are typically uninspectable for passage alignment, porosity, inclusions and measurements of the interior walls. TOMO was capable of providing quantitative data denoting the varying

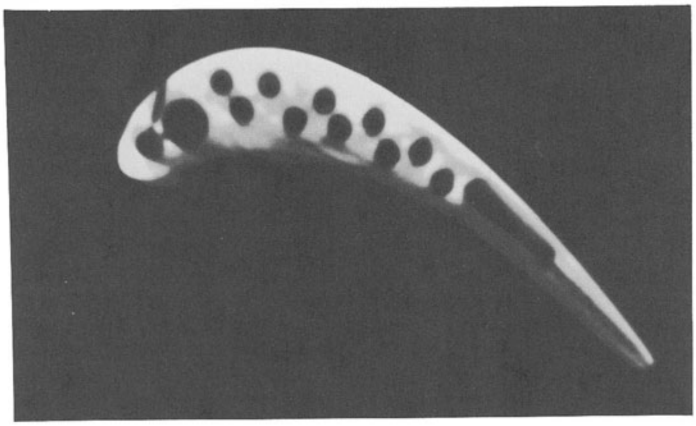

Figure 3. High resolution CT image of turbine blade.

sized holes present and the crack at the leading edge. CT is proving useful in the examination of turbine blades for dimensional tolerances, inclusions, core alignment and potentially dross detection.

CERAMIC FILTER

Ceramic filters are used in the processing of molten metals. The quality of the filter is determined by the distribution of the porosity in the material. It is necessary that the holes or voids within the ceramic are randomly distributed and do not permit a direct flow path through the filter.

Figure 4. is a CT image of a ceramic filter.[1] The dark regions represent void indications. Note the distribution of the voids in the material and the varying sizes are imaged very well with CT. Other forms of NDE, such as ultrasonics, would be ineffective due to the porosity levels, since the voids would block the sound waves and the ceramic edges would cause severe scatter. The internal structure of this material is visible nondestructively only with high resolution CT.

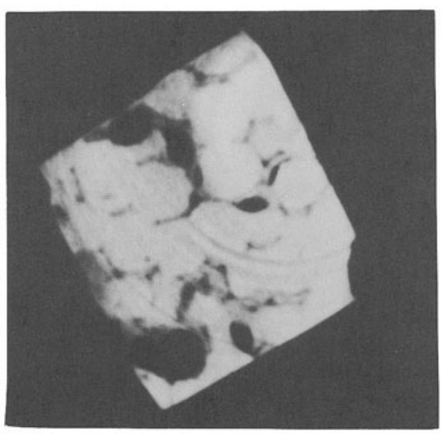

Figure 4. CT image of a ceramic filter.

SILICON CARBIDE COUPON

New materials are initially made in small coupon sized samples for the initial testing and experimentation. For a next generation propulsion application, a silicon carbide coupon has been developed to examine its capabilities to model the behavior characteristics experienced in a larger rotor assembly. This coupon contained laser drilled holes, to simulate aerodynamic stresses anticipated during the rotor's operation.

The NDE examination included both a digital radiographic and CT inspection. Figure 5a. shows the digital radiograph of the coupon with two CT slice locations indicated by white lines. Figure 5b., Slice 1, is through a plane containing the laser drilled holes. From the CT slice, the laser drilled holes are not uniform from front to back, but widen in diameter as the holes penetrate the material. Figure 5c., Slice 2, is through the whole material. The dark regions in the images are porosity in this material. This porosity is normal to the process under which the material is made and the manufacturer is interested in observing even dispersion of the porosity throughout this coupon specimen.

SYSTEM STANDARD

A standard, or phantom, is an object that is imaged for test purposes, measuring the response of the CT system. The resolution measurements are fundamental measures of a system. The scanning of a phantom provides a quantitative measure of the CT machine capability that can be used repetitively to assure consistent performance.

One method of evaluating the resolution of a CT system, is by scanning a line-pair resolution phantom. The phantom consists of sets of metallic and acrylic plates of specified thicknesses. These plates are arranged in 2, 4, 8 and 16 pairs of metal/acrylic plates per millimeter. [1] Figure 6. is an image from the Tomoscope CT system of the line pair gauge. Examining this image visually, the 8 lp/mm plates are clearly imaged and the 16 lp/mm plates are not discriminated. The resolution of the TOMO system is therefore between 8 and

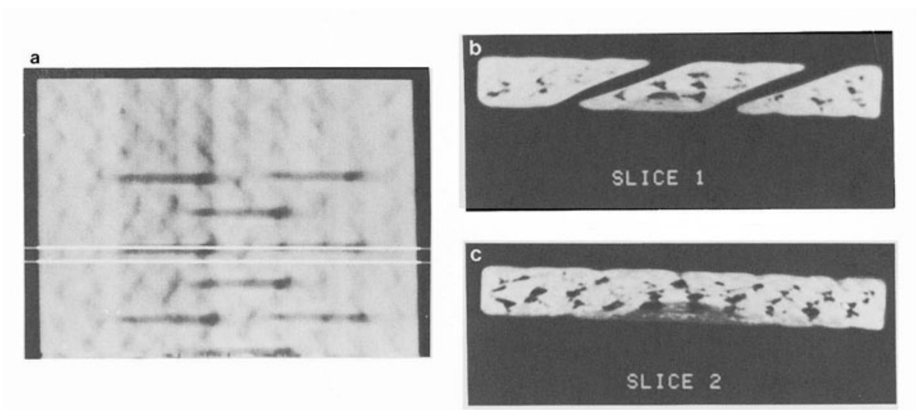

Figure 5. Digital radiograph and CT images of silicon carbide coupon.

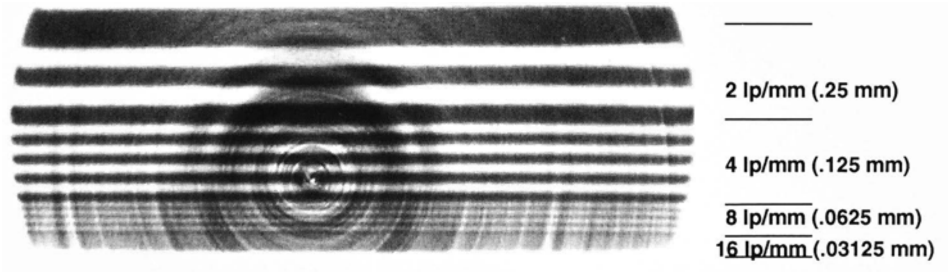

Figure 6. CT image of line pair gauge to determine Tomoscope CT system resolution.

16 line pairs per millimeter, between 62 and 31 micrometers. A rigorous analysis can be performed by measuring the modulation of the CT numbers resulting from a trace across the line pairs.[2]

CONCLUSION

These examples provided in this paper represent a cross-section of specimen types that have been investigated at the Wright Laboratory CT Research Facility. Material designers which have utilized this capability to date, have found this a valuable resource and support the continued development of this technology. This paper shows that the Tomoscope CT System can be very effective in imaging the interior structure of materials to assist in the characterization of the material, the manufacturing process and providing information to assist in determining the effects of defects.

Near term development plans for this system will be an upgraded detector package and higher energy X-ray source. The higher energy X-ray source will have a smaller focal spot size to support needs for smaller detection capability, less than 25 micrometer resolution, with the capability to examine larger, more dense materials with the higher energy. The detector package upgrade will include dual energy capability, or the ability to acquired data at two separate energy ranges. With the dual energy-range data, and some computational and comparative analysis in the reconstruction algorithms, chemical composition information can be obtained about the part under inspection. These advanced developments are anticipated to be installed by June 1993.

REFERENCES

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