628
doi:10.1017/S1431927613005138
Microsc. Microanal. 19 (Suppl 2), 2013

Micro-CT for Visualization of the Internal Structure of Industrial Materials

Anjali Singhal and Ying Zhou

Materials Characterization & Chemical Sensing, GE Global Research, Niskayuna, NY, USA

Micro-computed X-ray tomography (Micro-CT) has gained increasing importance in the field of 3D materials characterization and inspection because of its non-destructive nature. The CT data is used to generate 3D views of the internal structure, which would otherwise be obtained only by analyzing it destructively. State-of-the-art laboratory-based Micro-CT X-ray tube-based systems, although suffering from some limitations, are now at par with synchrotron-based high energy beam based CT approaches. The measurement speed and quality of the data obtained has resulted in this technique being widely used, not only in the medical community where it all began (for bones and tissue), but also in the vast area of materials science. In this paper, we describe several materials which are of interest to GE, and how Micro/Nano-CT is being used to characterize them. The tomography system used here is the vtomex M micro/nano-CT (GE Sensing and Inspection Technologies), which has a 300 kVp micro-focus source and a 180kVp nano-focus source.

Carbon-fibre reinforced polymer composites are being used as weight-saving for aluminium in several large aircraft engine parts. Because the geometry of many parts of interest is complex, it is of interest to investigate forming the laminate to these shapes after layup on a simpler tool. However such forming processes can create local imperfections in the laminate including delaminations and wrinkles. Investigation of parts thus made for such defects can be of great benefit in exploring the limits of the processes. An arc section of an axisymmetric formed composite part is imaged to identify defects in the ply layup forming process, such as the formation of any wrinkles, as well as ply angle changes that would be expected based on the starting and final geometries. This sample was imaged using the micro-focus source at 180kV tube voltage and 110µA filament current; the total acquisition time was 57 minutes. A nominal resolution of 33µm was obtained. The orientation of the fibre tows in this sample is +/- 45° and 0°/90°. The image in Figure 1 is a CT slice showing a cross-section of the composite in the axial-radial plane. The gaps between plies can be clearly seen in the outer corner of the formed radius. Other views confirm that the angles between the tows increase from the inner to the outer radius. This variation suggests that as the plies are formed to their final shape, the resin allows sliding between and within them, as explored for draping [1]. In order to understand the movement of the plies and check for the formation of wrinkles during the process of forming, we have performed an *in situ* forming study by imaging at various increments of pressure. The sample was formed within custom made tooling, in a furnace oven. At several intermediate steps in the process, CT was performed on the sample inside the tooling using the micro-focus source at 150kV tube voltage and a filament current of 110µA. The imaging parameters were selected to provide desired resolution of individual fiber tows while maintaining an acquisition time of 17 minutes that minimized transient effects after forming. A nominal resolution of 50µm was obtained. It was seen that the thickness of the laminate and the friction between the laminate and tooling play important roles in the quality of the formed part.

Nickel-based superalloys are commonly used in aircraft engine turbine blades. These blades are subjected to sustained-peak low-cycle fatigue (SPLCF) [2] due to the cyclic loading during the gas-turbine operation. CT serves as a valuable tool to locate and measure the cracks that form as a result of fatigue damage. Using Micro-CT, one can investigate the morphology and depth of large cracks that are formed as a result of testing. Such a measurement is difficult to do by traditional metallography techniques because of ambiguity in the location of sections to measure the deep cracks. Additionally the distribution of the cracks throughout the specimen can be obtained by Micro-CT. The SPLCF tested cylindrical dog-bone shaped fatigue samples (5 mm in diameter) were imaged using the micro-focus source at 180kV tube voltage, and a filament current of 60µA to obtain a nominal resolution of 11 µm. Long exposure times were required to penetrate the sample, resulting in an acquisition time of 4.5 hours for the 20 mm gage section of the specimen. This CT inspection is the first of its kind; it uses the high-power and the high-resolution capability of the particular instrument. Figure 2 shows the three deep cracks in a fractured sample. The cracks detected are of a typical thumbnail shape, and have propagated perpendicular to the direction of the applied axial stress.

In conclusion, CT has been proved as an indispensable tool for evaluating materials and components during any stage of their fabrication and post-testing. Samples of any size and geometry can be imaged with minimal sample preparation. As the scope for new applications of CT continually increases, there is a greater drive towards the development of more efficient X-ray sources, accurate reconstruction algorithms and higher spatial resolution as well as temporal resolution. Finally, the incorporation of other analytical modalities such as phase identification through EDS, in the CT systems would be revolutionary.

References:

[1] E-T Neoh, Master's Thesis, Massachussets Institute of Technology (1992).
[2] Suzuki, *et al*, Metallurgical and Materials Transcations A, Vol. 41A (2010), p. 947-956.

Figure 1. A CT slice of the cross-section of the formed composite. The width of the image is 29.0 mm to scale.

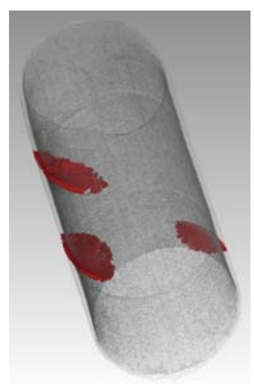

Figure 2. A 3D volume reconstruction of the fractured Ni-based superalloy specimen. The cracks are highlighted in red; the material is rendered transparent to aid in visualization. The width of the image is 8.7 mm to scale.

https://doi.org/10.1017/S1431927613005138 Published online by Cambridge University Press