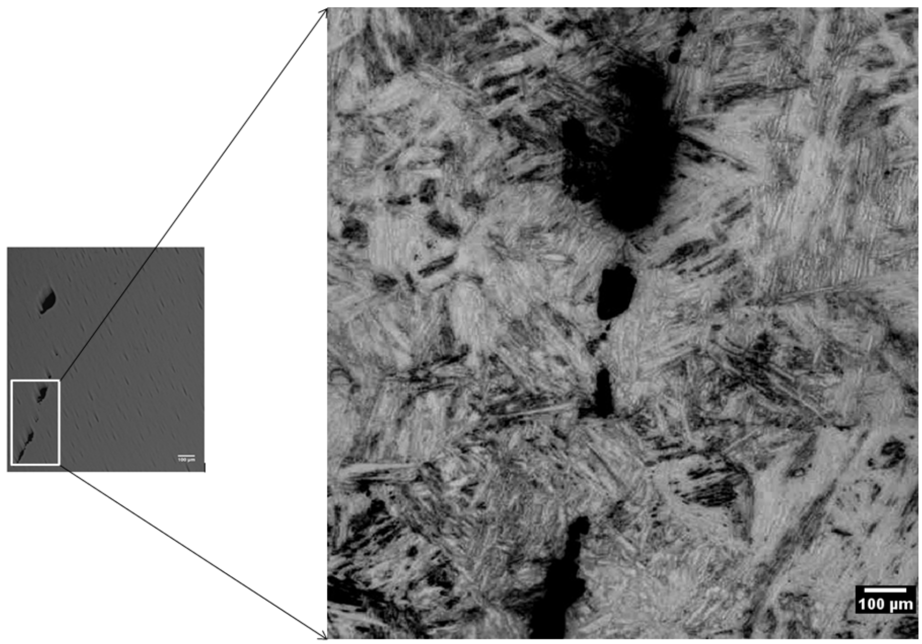
3D INSIGHTS



3/1/2017

Automated Step Polishing to Identify Features in JetHete Aerospace Alloy Billet

Contact ultrasonic testing (UT) initially flagged a feature in a JetHete alloy billet. Automated step polishing with Robo-Met.3D® was used to identify and characterize the size, location and orientation of the feature, in relation to the local microstructure. The feature was identified as a set of pores. No other microstructural anomalies were found near or around the features.

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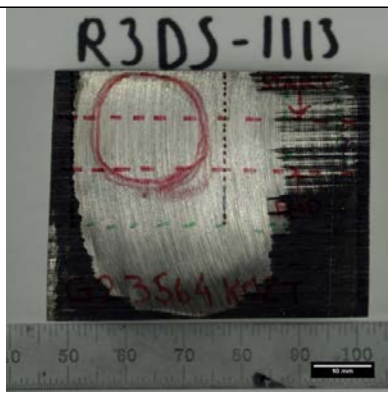
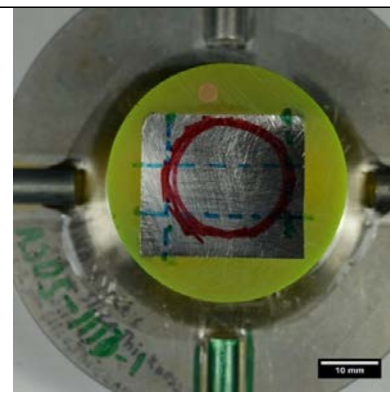
MATERIAL BACKGROUND

Due to the high safety standards for applications in the aerospace industries, plates which are used as a raw material for components have to undergo an ultrasonic inspection. In order to reach the safety standards, the material has to be free of inclusions above a critical size[i]. In this application note, we describe the localization and characterization of an inclusion in JetHete (a martensitic stainless steel aerospace alloy), originally identified by contact ultrasonic testing. Because of the temper resistance this alloy is often used as high heat bolting in the aerospace industry and gas turbine parts in the power generation industry.

The alloy was provided by Universal Stainless (Bridgeville, PA), as a sectioned piece. Ultrasonic testing had localized a feature in the billet, but did not further characterize the feature. The area that the feature was localized to by ultrasonic testing was marked off to aid analysis (Fig. 1). The original specimen dimensions were 52.43 mm X 42.54 mm X 18.54 mm, and the region of interest was about 17 mm in diameter.

Fig. 1: Sample As-Received	Fig. 2: Mounted Sample
	

AUTOMATED SERIAL SECTIONING ANALYSIS USING ROBO-MET.3D®

Robo-Met 3D® is a fully automated, serial sectioning system for three-dimensional microstructural investigations. The system sequentially grinds and polishes away layers of material with high accuracy. This enables metallographic etching and imaging of the microstructure of materials. Post-processing reassembles these 2D images, gathered over an optical scale, into 3D models. Common applications of Robo-Met.3D include studying additively manufactured components[ii], analysis of welds and thermal barrier coatings[iii], and fiber orientation effects in ceramic matrix composites[iv]. The work reported here is a further expansion of the Robo-Met.3D system capabilities, applicable where time and resource efficiencies are achieved by automated step polishing.

To prepare the sample for automatic step polishing, the specimen was mounted in epoxy. About 2.3mm (90 mils) of the specimen were manually ground down with 80 grit (~200 μm) SiC paper, to remove the visible wear track. The specimen was mounted in the Robo-Met polishing chuck, and the bounds of the imaging mosaic were defined around the region of interest before polishing (Fig. 2). The specimen was planarized at each slice with 120 grit diamond fixed abrasives, automatically polished with 6 µm, 3 µm, and 0.25 µm diamonds, and finished with 0.05 µm colloidal silica (Fig. 3).

A very linear material removal rate of ~ 33 µm per slice was achieved (Fig. 4). The step size for this automated system is programmed depending on the indication size and orientation. Universal Stainless employed a tightest rejection standard of a 2/64th FBH (~793.7 micron Flat Bottom Hole), and wanted to section through that with some level of buffer due to uncertainties with the accuracy of pinpointing via contact UT. This was in keeping with UES' practice of taking ten sections through a desired feature of interest. The 33 micron step size achieved both these objectives, and as the results will show, provided good characterization.

Fig. 3: Material Removed by Manual Planarizing vs. Automatic Removal

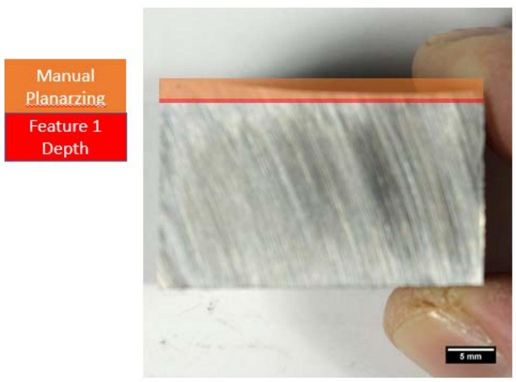
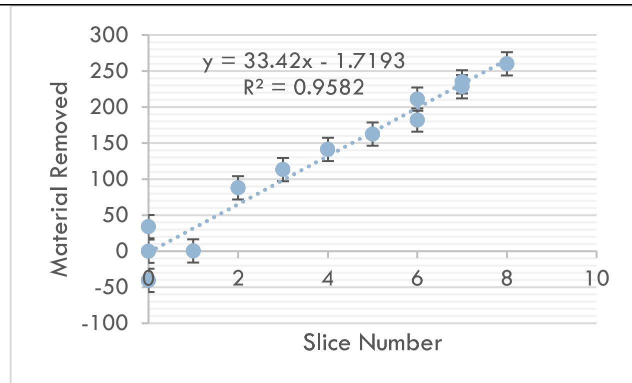


Fig. 4: Linearity of Step Polishing



All imaging was performed with an overall magnification of 50x. The feature was directly observed for 7 slices, through a depth of 235 µm (~9.25 mils, Fig. 5). The object was passed though by the 8th slice, at the depth of 260 µm (10.24 mils). The specimen was swab etched with waterless Kallings reagent between the 7th and 8th slice, to reveal the microstructure (Fig. 6). Automated detection of the feature by image analysis is a future development target.

Fig. 5: 2D Image of Feature

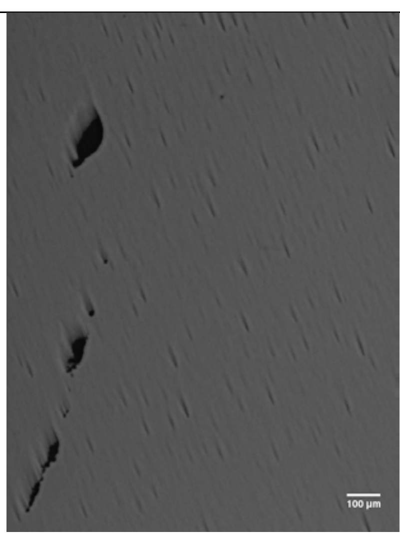


Fig. 6: 2D Image with local microstructure for context

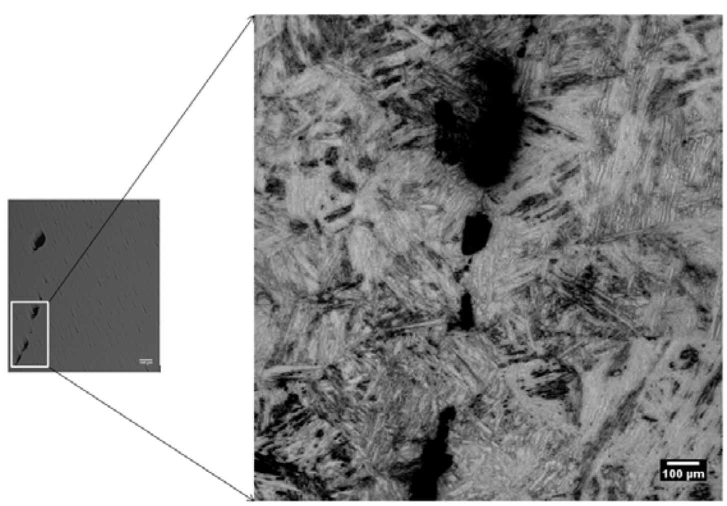


IMAGE PROCESSING AND ANALYSIS

Optical images were automatically acquired with the microscope built into the Robo-Met.3D system, at a magnification of 50x. The resultant spatial resolution was 2.1 µm along X and Y axes. Seven slices of 88 image tiles (an 8x11 montage) each were collected for 3D reconstruction. The image pixel sizes from this collection (after stitching and alignment) were 1025 µm along X; 448 µm along Y, after images were cropped to exclude unwanted regions. The 2D image tiles from each layer were stitched into mosaics and then registered with the images from the next layer using Fiji and Image J software.

Fig. 7: Volume Reconstruction

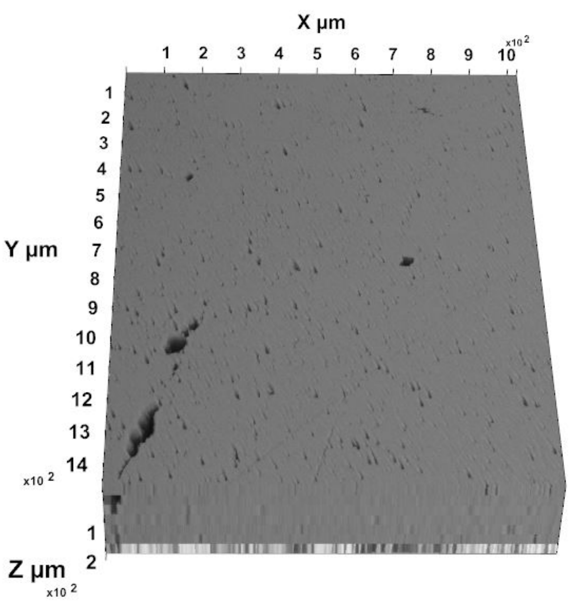
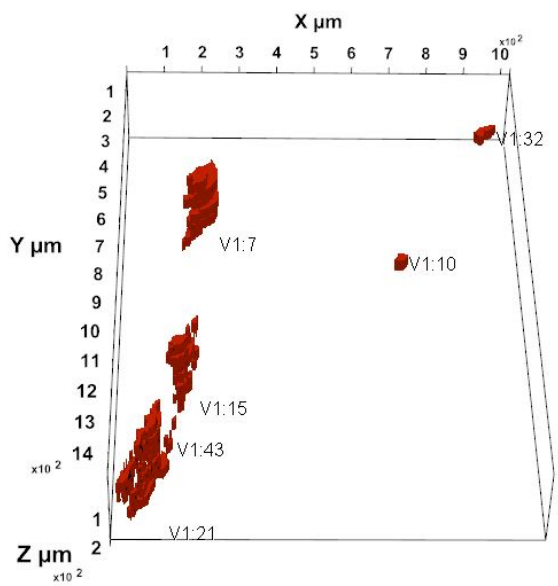


Fig. 8: 3D Model of Porosity



For 3D analysis, the loaded z-stack of 7 slices was processed with full resolution along X, Y and Z directions. A 3D isosurface was created without any filtering. An image histogram was used to threshold the pore and matrix phases. The segmented images and resultant volume reconstruction were analyzed for feature size quantification (Fig. 7, 8). The volumetric conclusions (with ~ 1% error) are presented in Table 1 below.

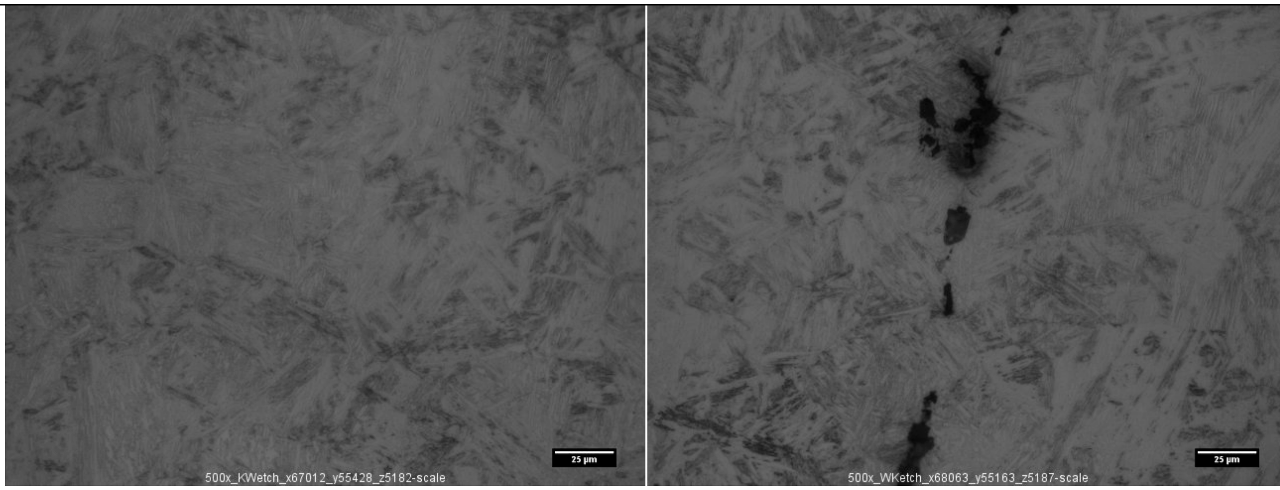
Table 1: Volumetric Analysis of the Regions

Feature Name	Volume(µm^3)	Width(µm)	Height(µm)	Depth(µm)	Volume Percentage
V1:7	927608.1	96.6	184.8	231.0	0.27
V1:10	20228.7	35.7	27.3	33.0	0.01
V1:15	324240.7	79.8	115.5	231.0	0.09
V1:21	571787.3	117.6	252.0	231.0	0.17
V1:32	36964.6	58.8	46.2	33.0	0.01
V1:43	13825.4	29.4	44.1	99.0	0.00

DISCUSSION

The feature was identified to be a set of pores. No microstructural anomalies were found near or around the features. Microstructure immediately around the feature was composed of martensite with lath of similar morphology to those found up to a millimeter away from the feature (Fig. 9). The microstructure of the 8th slice, which was ~33 µm deeper into the specimen, was also of a similar morphology.

Fig. 9: No microstructural anomalies were found near or around the features.



CONCLUSIONS

The Robo-Met.3D system was able to automatically and accurately step-polish the sample with a high level of linearity. Microstructural analysis identified the feature as a set of pores, which prior UT had not been able to identify. Two recent studies also suggest that this technique is valuable in additive manufacturing applications, in comparison to conventional 2D metallography[v], as well as laser ultrasound and CT methods[vi].

CONTRIBUTORS

Bryan Turner (UES), and Satya Ganti (UES) performed the image collection and post-processing. We are grateful to Dr. Graham McIntosh, Jeanne Treasurer, and D. Jay Geibel of Universal Stainless Inc. for the JetHete sample, and collaboration in writing this note. Animated views of the data are available at www.ues.com.

REFERENCES

[i] Prillhoffer, B., Antrekowitch, H., Böttcher, H, Enright, P. (2008) Nonmetallic Inclusions In The Secondary Aluminum Industry For The Production Of Aerospace Alloys: Light Metals 2008, De Young D., ed., TMS, 2008.

[ii] Seifi, M., Ghamarian, I., Samimi, P., Collins, P. C., & Lewandowski, J. J. (2016). Microstructure and mechanical properties of Ti-48Al-2Cr-2Nb manufactured via electron beam melting. In *Ti-2015: The 13th World Conference on Titanium*.

[iii] Madison, J. D., Huffman, E. M., Poulter, G. A., & Kilgo, A. C. (2015). *R3D at Sandia National Laboratories-A User Update* (No. SAND2015-7665PE). Sandia National Laboratories (SNL-NM), Albuquerque, NM (United States).

[iv] Bricker, S., Simmons, J. P., Przybyla, C., & Hardie, R. (2015, March). Anomaly detection of microstructural defects in continuous fiber reinforced composites. In *SPIE/IS&T Electronic Imaging* (pp. 94010A-94010A). International Society for Optics and Photonics.

[v] Ganti, S., Velez, M., Geier, B., Hayes, B., Turner, B., & Jenkins, E. (2017). A Comparison of Porosity Analysis Using 2D Stereology Estimates and 3D Serial Sectioning for Additively Manufactured Ti 6Al 2Sn 4Zr 2Mo Alloy. Practical Metallography, 54(2), 77-94.

[vi] Everton, S., Dickens, P., Tuck, C., Dutton, B., & Wimpenny, D. (2017). The Use of Laser Ultrasound to Detect Defects in Laser Melted Parts. In TMS 2017 146th Annual Meeting & Exhibition Supplemental Proceedings (pp. 105-116). Springer International Publishing.