Application Note

Instruments: Met and Optical Overview

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Metallography of Aluminum and Aluminum Alloys

LECO Corporation; St. Joseph, Michigan USA

Introduction

Aluminum has become a widely used material due to its natural corrosion resistance (oxide layer), manageable weight, high thermal conductivity, and cost-effective machinability. Pure Aluminum is too soft for structural use, so it is often alloyed with other metals such as Copper, Magnesium, Silicon, Zinc, and Manganese to increase its strength and durability for aerospace, automotive, and construction applications. Metallography is an important tool for verifying quality control properties in these materials, including grain size, intermetallic phases, precipitates, and porosity, all of which affect mechanical properties, corrosion resistance, and electrical conductivity. LECO offers complete metallographic solutions made to streamline and optimize every step of the sample preparation process from start to finish.

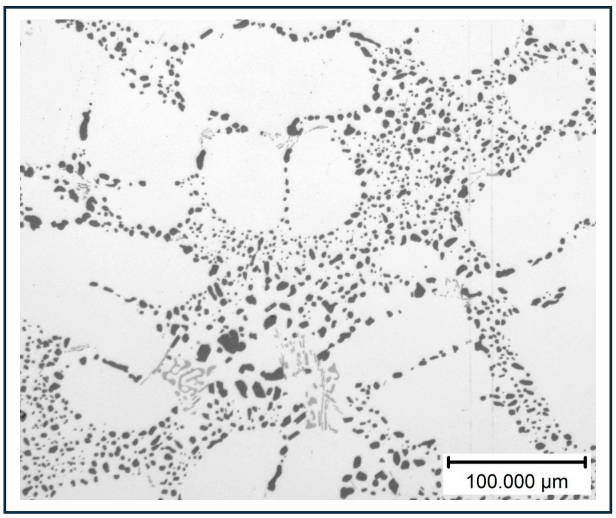

Figure 1. Aluminum-Silicon Alloy (20X Objective on LECO VX5).

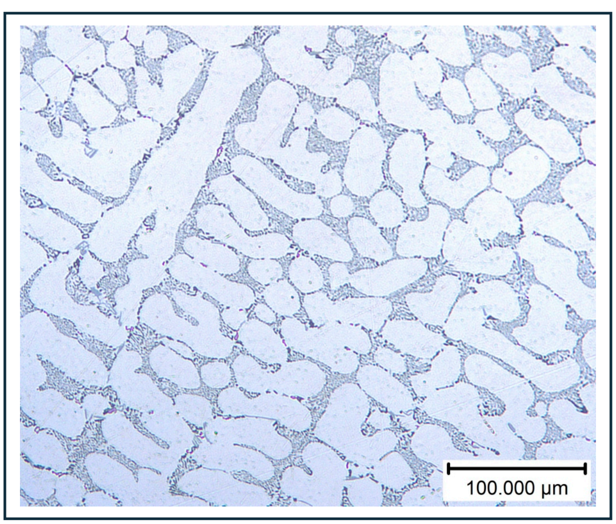

Figure 2. Aluminum (20X Objective on LECO VX5).

Revealing and Understanding Microstructure in Aluminum

Porosity (internal or surface voids), is a critical point of inspection for Cast Aluminum products to ensure structural integrity and surface quality. If not controlled, it can lead to reduced tensile and fatigue strength, increased risk of cracking, machining defects, rejected parts, and higher scrap rates.

One way pores form is from shrinkage. Shrinkage porosity occurs when the molten metal cools and its density increases, causing the material to contract slightly during solidification. Aluminum and its alloys generally have the highest shrinkage rates among casting metals, often up to 6-7%. As space opens from this shrinkage, pores are formed that can be filled by nearby molten metal or become permanent if no liquid is available nearby.

Another way pores form is from trapped gas. Molten metal often absorbs high amounts of gases such as Oxygen, Nitrogen, and Hydrogen at high temperatures. As it solidifies, it may struggle to release these gases which results in pores. Contrary to the pores from shrinkage, it is not just empty space. The pores are filled with the respective gases that were not released prior to solidification.

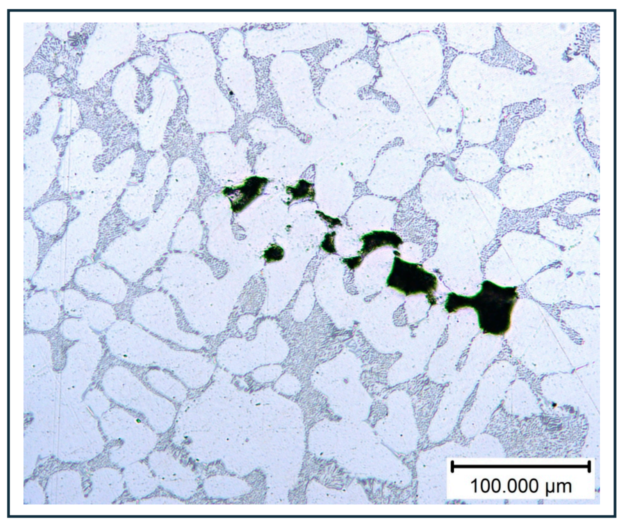

Figure 3. Shrinkage Porosity in Aluminum Sample (20X Objective on LECO VX5).

Sample Sectioning

With any metallographic sample, the most critical step of sample preparation is sectioning. The goal of sectioning is to remove a suitable-sized sample from a larger component with the least amount of deformation. If done incorrectly, thermal damage may occur to the sample's surface, requiring extra steps in the grinding/polishing phase. It could even affect the sample's microstructure, resulting in skewed image analysis results. In extreme cases, it may even require an operator to resection the sample, leading to additional costs and loss of valuable time. To increase efficiency, it is important to choose the correct blade and fixture for your sample.

LECO recommends the use of a Silicon Carbide blade (SiC) for sectioning Aluminum alloys, as they are designed for soft non-ferrous metals, allowing minimal deformation and efficient heat dissipation. The SiC abrasives prevent smearing and tearing, outperforming harder Iron-focused blades on Aluminum structure. LECO offers a variety of fixturing options to accommodate even the most difficult geometries for sectioning (Figures 4 and 5). Fixturing the sample properly is critical to stabilize the sample to prevent unnecessary vibrations and release of the sample during the cutting process.

If thermal degradation occurs after taking these necessary measures, it could be the sectioning method. Although chop cutting (Z-Axis) is the traditional form of operation with sectioning saws, it may be advantageous to try a pulse or planar cut that would provide more relief in the process. This could also be the case for an Aluminum part with complex geometry.

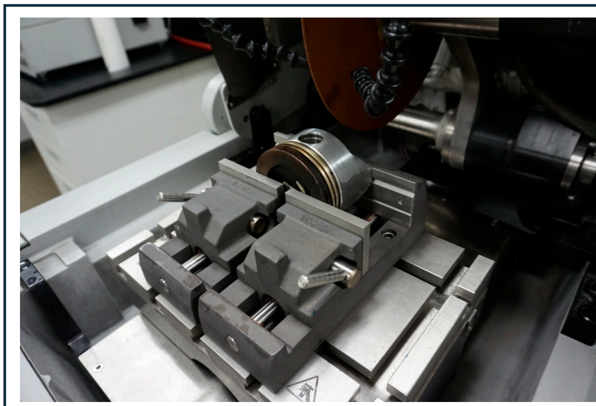

Figure 4. Aluminum Piston Fixture using Cam-Lock vises on LECO CX300.

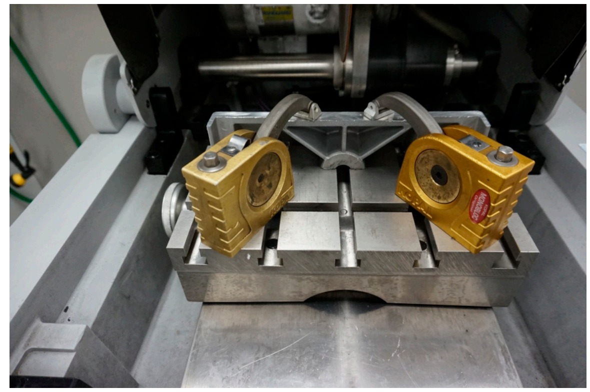

Figure 5. Aluminum Stand Fixtured using Clamping Fingers on LECO CX300.

Mounting

Mounting the aluminum sample for grinding and polishing is advantageous as it secures small and irregular shapes, enables automated handling, protects edges from rounding, and ensures a flat, uniform surface for microstructure analysis. For the best adhesion of mounting material to the sample, the sample should be clean and free of sharp edges. LECO offers both hot mounting and cold mounting options for Aluminum-based samples.

For high sample throughput labs that have thick samples and don't anticipate sensitivity to temperature, Bakelite (Figure 6) or Epoxy in a hot mounting press are recommended. One may even use Epoxy to cover the sample and backfill the remainder of the mount with Bakelite to increase edge retention and decrease shrinkage while minimizing costs. For samples that are thin or sensitive to temperature or pressure, cold mounting in a castable mount is recommended. If time is a priority, an Acrylic resin would be the best choice paired with a pressure vessel for increased edge retention and transparency (Figure 7). If time is not a priority and the sample has increased porosity/voids, an Epoxy resin is recommended due to its low viscosity, allowing it to deeply penetrate, seal, and fill microscopic pores. With long cure epoxies, it is often recommended to use a vacuum chamber to fill those voids and remove any entrapped air. Table 1 provides examples of various mounting configurations.

Table 1. LECO Mounting Options.

Mounting Material	Recommended Instrumentation	Estimated Cycle Time	Recommended For
Bakelite/Epoxy	LECO MX Series	~6-7 minutes	High Sample Throughput Thick Samples
Acrylic Resin (LECOSET 7008 or LECOSET 100)	LECOMAT Pressure Vessel	~10-15 minutes	Temperature/Pressure Sensitive Samples Thin Samples
Epoxy Resin (Quick Cure or Long Cure)	Long Cure: Vacuum	Quick Cure: 2-3 hours Long Cure: 8-12 hours	Temperature/Pressure Sensitive Samples Thin Samples High Porosity

Figure 6. Bakelite Hot Compression Mount from LECO MX400.

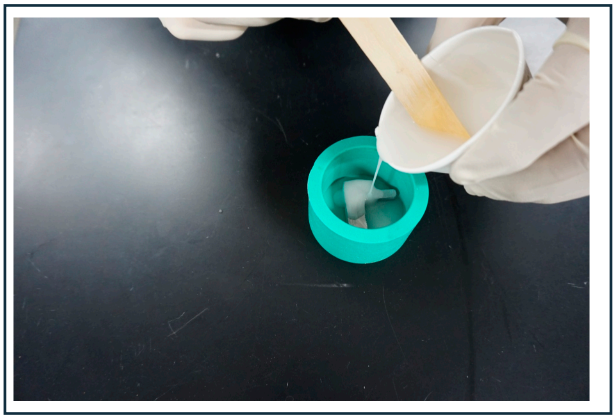

Figure 7. Acrylic Cold Mount with LECOSET 7008.

Grinding & Polishing

Grinding

The goal of grinding is to remove any deformation caused by previous preparation steps and produce a scratch-free surface. In this step, it is very important to avoid any pull-outs, thermal damage, or foreign elements that could cause additional surface deformation. LECO recommends Premium Silicon Carbide (SiC) Papers for Aluminum sample preparation due to its high hardness, sharp cutting action, and friable nature, allowing for rapid material removal with minimal deformation on soft metals. Since Aluminum is inherently soft and susceptible to deformation, using overly aggressive or improper abrasives can introduce artifacts that compromise the microstructure (Figures 8, 9, and 10). Water should be added to help minimize the heat buildup in this process as well as wash away any grit or debris that's created to prevent buildup. All these necessary measures will help to avoid excess deformation and embedding the sample. Any scratches or foreign materials introduced on the surface could cause inaccurate porosity results and microstructure observations.

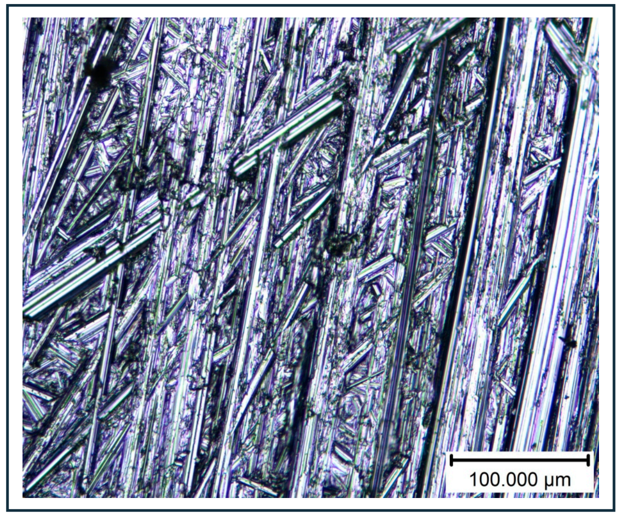

Figure 8. 240 Grit SiC (20X Objective on LECO VX5).

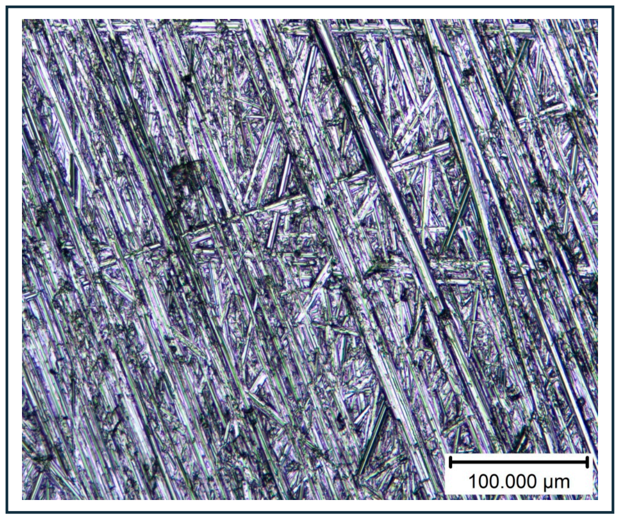

Figure 9. 400 Grit SiC (20X Objective on LECO VX5).

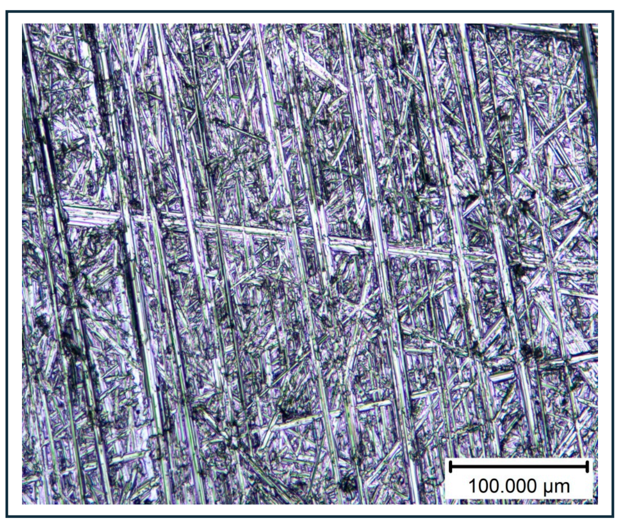

Figure 10. 600 Grit SiC (20X Objective on LECO VX5).

Polishing
Polishing is conducted in metallography to create a mirrorlike and deformation-free surface, removing scratches and damage left by grinding. This critical step ensures that the true microstructure is visible, allowing for accurate microscopic analysis, testing, and interpretation without artifacts that could distort the results. LECO recommends three fine polishing steps to achieve the desired result: 3 μm, 1 μm, and 0.05 μm. These steps will properly remove any scratches that may have been introduced in grinding. Between each step, it is recommended to gently clean the sample's surface and air dry to avoid cross-contamination of each cloth's designated solution. The 3 μm and 1 μm steps utilize diamond suspension or paste solutions and an extender (Figures 11 and 12).

The use of a fluid extender (lubricant) is advised to decrease friction, facilitate heat dissipation, prevent abrasive clogging, and promote uniform distribution of diamond compounds or suspensions. It also keeps the polishing cloth moist, improves material removal efficiency, prevents sample damage, and ensures consistent surface finishes. The final polishing step utilizes a 0.05 μm colloidal silica due to its combination of chemical polishing and fine mechanical action, producing a damage-free, scratch-free, and deformation-free surface (Figure 13). A solution of ~50 mL ammonium hydroxide and ~5 mL hydrogen peroxide can be added dropwise to the polishing wheel to increase the chemical reaction.

Cornerstone Software
LECO's Cornerstone Metallography Series software is supplied with many common methods, including one with parameters specified for preparation of Aluminum, which guides the user through each step (Figure 14). These methods can also be easily edited and customized to the user's preferences.

Cornerstone Series Simulator:
https://www.lecosoftware.com/metallographics/px

Figure 14. PX Series Cornerstone Software.

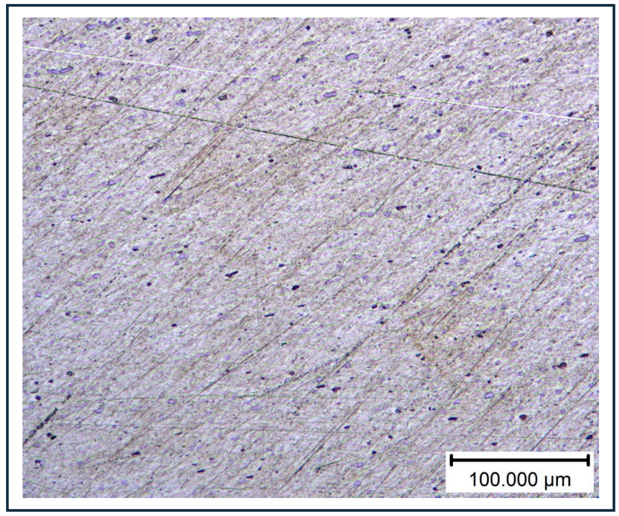

Figure 11. Gold Technotron - 3 µm (20X Objective on LECO VX5).

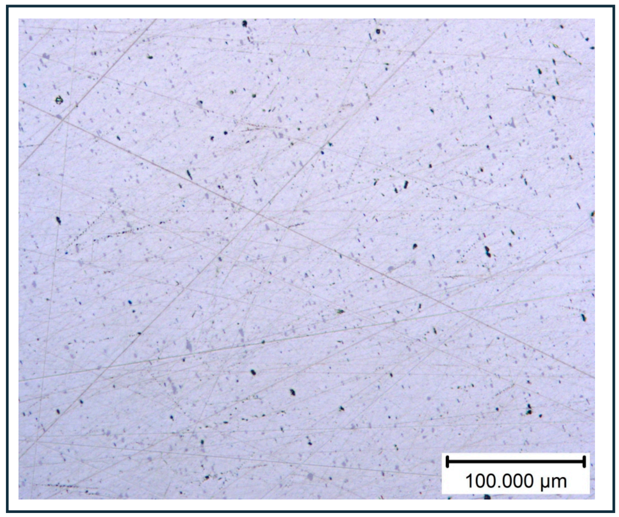

Figure 12. Red Felt - 1 µm (20X Objective on LECO VX5).

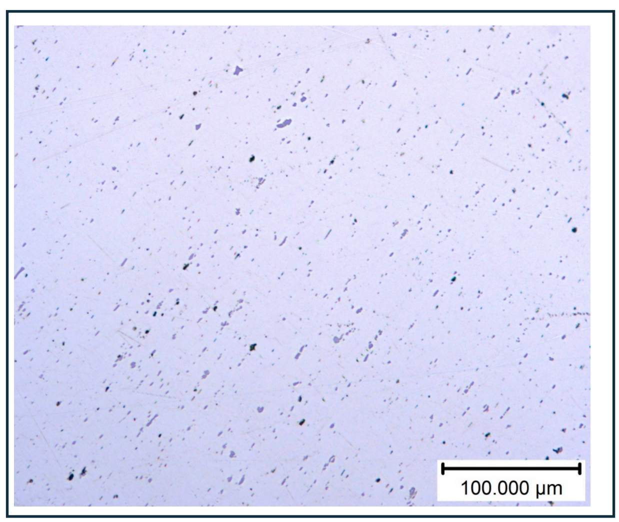

Figure 13. Imperial - 0.05 µm (20X Objective on LECO VX5).

Table 2. LECO Polishing Guidelines.

	Time (Min:S)	Head Direction	Head Pressure (lbf)	Head Speed (RPM)	Wheel Direction	Wheel Speed (RPM)
240 grit SiC / H_2O	1:00	CCW	40	100	CCW	200
400 grit SiC / H_2O	1:00	CCW	40	100	CCW	200
600 grit SiC / H_2O	1:00	CCW	40	100	CCW	200
Gold Technotron / 3 μm Diamond Suspension / Extender	3:00	CCW	30	100	CCW	200
Red Felt Cloth / 1 μm Diamond Suspension / Extender	1:00	CCW	30	100	CCW	200
Imperial Cloth / 0.05 μm Colloidal Silica	1:00	CCW	20	75	CCW	150

Image Analysis for Porosity Quantification

LECO's image analysis software, PAX-it, provides users with an enhanced user interface to automate and generate reports based on common metallographic inspections for Aluminum, including porosity and dendrite arm spacing. For most Aluminum applications, samples in the as-polished condition are suitable for microstructure observation as well as the previously mentioned inspections. (Figure 15).

With the "Detect Areas" capability, users can accurately quantify porosity from a captured image. It is often recommended to use multiple images and areas of a sample for an accurate average of the entire sample. During the analysis, the software will detect different colored areas based on the user-defined passes to show what items are being identified as pores (Figure 16). A thresholding bar allows the user to adjust the sensitivity of the detection to better fit what is being observed if necessary (Figure 17). After confirmation that the threshold matches the pores observed, the summary data will populate within the software. Users also have the option to customize and print out Excel reports for traceability purposes.

If etching is required for image analysis, LECO has a few recommendations based on the specific purpose. For general microstructure or grain structure, Keller's Reagent will help reveal these features not shown under the microscope as-polished. If color contrast microstructures are desired for grain orientation or texture analysis, Barker's Reagent (Electrolytic) is recommended with a polarized light mode for the microscope. For macrostructural evaluation, a 10-15% sodium hydroxide etch can help reveal flow lines, cold work, and any cracks.

Safety Note: Many popular Aluminum etchants contain hydrofluoric acid and/or other strong acids, so proper precautions should be taken. Refer to any SDS sheets provided with the products for recommendations on safe handling and storage.

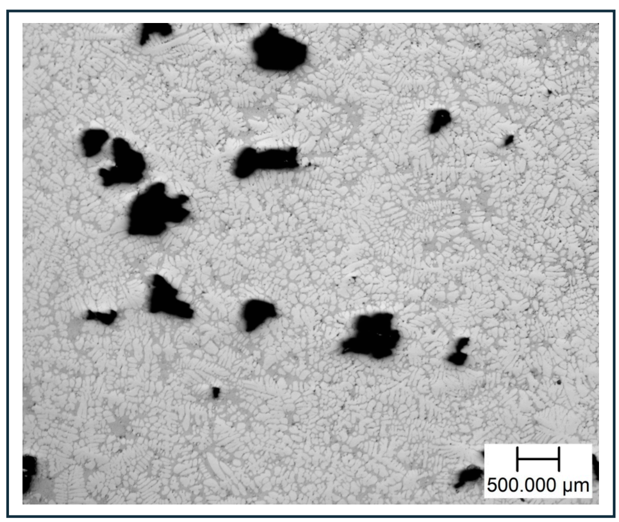

Figure 15. Aluminum with Porosity (1.25X Objective on LECO VX5).

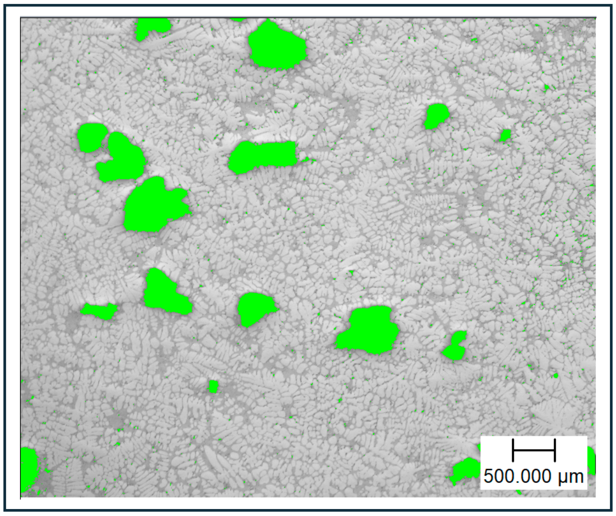

Figure 16. PAX-it "Detect Areas" Pass Applied.

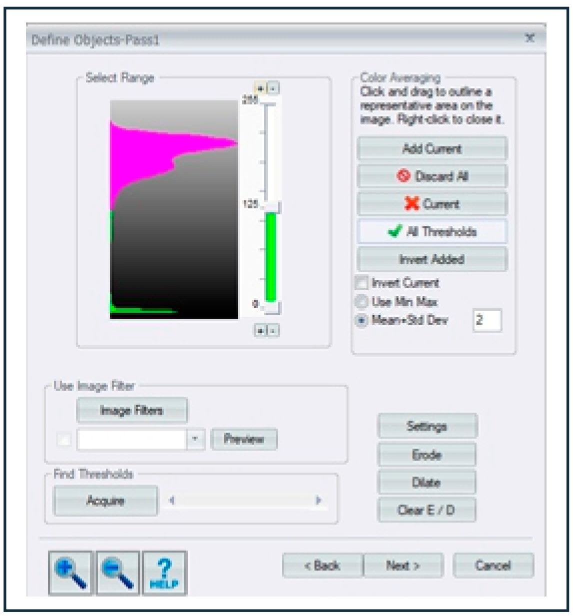

Figure 17. PAX-it Adjustable Threshold Applied to Image.

Conclusion

In summary, Aluminum and its alloys remain essential to modern engineering due to their lightweight nature, corrosion resistance, and adaptability. Ensuring these materials meet the demanding requirements of aerospace, automotive, and structural applications depends on precise metallographic evaluation. By characterizing grain structures, intermetallic phases, precipitates, and porosity, metallography provides critical insight into material performance, durability, and quality.

LECO supports this process with a full suite of metallographic solutions designed to enhance efficiency and consistency at every stage of preparation. From robust sectioning systems that ensure clean, controlled cuts, to reliable mounting equipment that protects and preserves sample integrity, LECO enables repeatable, high-quality preparation. Our advanced grinding and polishing platforms deliver uniform, scratch-free surfaces ready for evaluation, while our comprehensive image analysis software provides accurate, data-driven characterization of microstructural features. Together, these tools offer a streamlined, end-to-end workflow that empowers laboratories to maintain stringent quality control and achieve confident, repeatable results.

LECO Metallographic Solutions

CX300 Series

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PAX-IT

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